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TECHNICAL MANUAL

Geotechnical Analysis for Review of Dike Stability (GARDS)

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16. ABSTRACT

A user-friendly, interactive computer program is designed to guide a geotechnical non-specialist (EPA regulatory personnel) through the customary steps of earth dike analysis considering slope stability, settlement, liquefaction, hydraulic flow and pressure conditions, and piping. The GARDS package is designed for use on the IBM-PC/XT microcomputer. The significant differences between GARDS and other slopes stability programs commonly available are the opportunity to perform all of the automatic search routine to determine the critical failure surface for both rotational (slip circle) and translational (wedge) stability analyses; and internal, automatic search routine to locate zones of greatest liquefaction potential and to compute total and differential settlements of foundation soils; an internal finite element hydraulic analysis to determine the steady state piezometric surface through the section, including the case of an impermeable barrier such as clay liner; the ability to model excess pore pressure conditions produced by confined steady state flow and evaluate slope stability and uplift conditions resulting therefrom; and the ability to determine the critical exit gradient and the potential for piping failure. User documentation consists of a combined Handbook/User's Manual (under development) which presents basic theory, program operational procedures, and example long hand and computer solutions for each analysis.

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NOTICE

The research described in this document has been funded wholly or in part by the United States Environmental Protection Agency. It has been subjected to Peer and Administrative Review and has been approved for publication as an EPA document.

This document is intended for use by professionals trained in the geotechnical methods which it covers. It does not include sufficient technical background and longhand example solutions to be characterized as suitable for use by nonspecialists.

This program has been verified only with respect to the numerical example(s) given. The user accepts and uses this program material at his own risk, relying solely upon his own inspection of the program material and not upon any representation or description concerning the program material.

Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of solid and hazardous wastes. These materials, if improperly dealt with, can threaten both public health and the environment. Abandoned waste sites and accidental releases of toxic and hazardous substances to the environment also have important environmental and public health implications. The Hazardous Waste Engineering Research Laboratory assists in providing an authoritative and defensible engineering basis for assessing and solving these problems. Its products support the policies, programs and regulations of the Environmental Protection Agency, the permitting and other responsiblities of State and local governments and the needs of both large and small businesses in handling their wastes responsibly and economically.

This report describes a computer software tool developed for regulatory use in the design and permitting of surface dikes at hazardous waste disposal sites. The program addresses the basic geotechnical aspects of earth dike stability.

For information, please contact the Land Pollution Control Division of The Hazardous Waste Engineering Research Laboratory.

Thomas R. Hauser, Director

Hazardous Waste Engineering Research Laboratory

ABSTRACT

The structure and capabilities of a user-friendly, interactive computer program developed for the stability analysis of dikes (GARDS) are described. The program was developed under the sponsorship of the U. S. Environmental Protection Agency and therefore emphasizes Hazardous Waste applications although it is suitable for general use. It is designed to guide regulatory personnel who have a geotechnical background through the customary steps of earth dike analysis considering slope stability, settlement, liquefaction, hydraulic flow and pressure conditions, and piping. The GARDS software is designed for use on the IBM-PC/XT, PC/AT, or compatible microcomputer.

The significant differences between GARDS and other slope stability programs commonly available are the opportunity to perform all of the above analyses in a single user-friendly, interactive package. GARDS includes an internal automatic search routine to determine the critical failure surface for both rotational (slip circle) and translational (wedge) stability analyses; an internal, automatic search routine to locate zones of greatest liquefaction potential and to compute total and differential settlements of foundation soils; an internal finite element hydraulic analysis to determine the steady state piezometric surface through the section, including the case of an impermeable barrier such as a clay liner; the ability to model excess pore pressure conditions produced by confined steady flow and evaluate slope stability and uplift conditions resulting therefrom; and the ability to determine the maximum exit gradient which defines the potential for piping failure.

User documentation consists of this Technical Manual which includes program operational procedures, example computer solutions for each analysis, and recommended minimum safety criteria.

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GARDS TECHNICAL MANUAL

1.0 INTRODUCTION

1.1 General

This Manual is intended to accompany the menu-driven GARDS software package for design review of earth dike stability. It details the basic technical concepts and operational procedures for the analysis of site hydraulic conditions, dike slope and foundation stability, dike settlement, and liquefaction potential of dike and foundation soils. It is designed to meet the expressed need for a geotechnical software support tool to facilitate evaluation of existing and proposed earth dike structures at hazardous waste disposal facilities.

GARDS is interactive, user-friendly, and designed for use by permit writers who have a geotechnical background. Both the software and this support documentation contain text explanations and graphic examples designed to guide the user through the customary steps of earth dike analysis. User-friendliness is accomplished through the use of menu selection of available program options, including data check and simplified editing procedures, automatic internal check of input parameter values, cautionary statements regarding the recommended sequence of program options, and error diagnostic statements with interactive instructions for corrective action.

GARDS incorporates two primary computer programs available in the public domain. REAME (Rotational Equilibrium Analysis of Multilayered Embankments; Y.H. Huang, University of Kentucky) is the base program to which the other program blocks have been adapted. SEEP (hydraulics analysis; K.S. Wong and J.M. Duncan, Virginia Polytechnic Institute) is used to determine site hydraulic parameters prior to slope stability or other analysis. Both programs have been modified to meet the interactive and user-friendly objectives of GARDS. All other control and analytical blocks were developed under this contract.

The slope stability block of GARDS offers the two-dimensional Simplified Bishop Method of slices (REAME) and a translational (WEDGE) analysis procedure published by the U.S. Department of the Navy in the May 1981 NAVFAC DM-7.1 design manual. Other limit-equilibrium analysis methods are not available in GARDS either because they were not available in the public domain, or were not amenable to efficient modification.

The GARDS package is a multi-diskette software package. It may be installed only on IBM-PC/XT, PC/AT, or compatible systems with a hard disk, the IBM color graphics adapter or compatible graphics card, and an IBM graphics compatible dot matrix printer.

The program will operate without a color graphics adapter or card but the user will not be able to view several graphical aids built into the program, and will not be able to view a scaled section view of the slope geometry prior to analysis. Also, an Epson (or compatible) dot matrix printer is required to obtain hard copy of graphic output. If such is not available, the user may substitute any parallel printer to obtain tabular output from the hydraulic analysis subroutine (required), but will not be able to obtain graphic output.

1.2 Perspective

All computer software is subject to misuse. This package is no exception. The validity of results obtained through the use of GARDS is directly proportional to the quality of the data upon which the analysis is based and the ability of the user to recognize situations where customary engineering assumptions are not appropriate. GARDS is comprehensive only in the sense that it addresses several analytical needs in one interactive package. It cannot be considered fail-safe, and its use will not guarantee safe design. The GARDS package is not an "expert system," but is suitable for use as a design tool or a design review tool by those who have been trained in its use, understand the underlying principles, and are aware of its limitations. Moreover, GARDS is suitable for use only when data describing site conditions and soil parameters have been supplied by geotechnical professionals. As a practical rule of thumb, a two-dimensional stability analysis is intended to serve as a guide to determine, with a reasonable degree of certainty, that an existing or proposed design meets or exceeds accepted minimum safety criteria under anticipated service conditions.

WITH THE FOREGOING AS BASIS, IT IS EXPRESSLY RECOMMENDED THAT ALL USERS STUDY THIS MANUAL ALONG WITH THE INTERACTIVE SOFTWARE AND SUCCESSFULLY REPLICATE THE PROVIDED EXAMPLES PRIOR TO THE APPLICATION OF GARDS IN THE DESIGN REVIEW PROCESS.

2.0 PROJECT OVERVIEW

2.1 Objective

The objective of the study was to develop a "user-friendly," interactive computer program to guide a permit reviewer through the customary steps of evaluating the stability of earth dike systems used in the land disposal of hazardous wastes. Section 264.221 (d) of the 40 CFR, Part 264, Land Disposal Regulations published in the *Federal Register* states: "A surface impoundment must have dikes that are designed, constructed, and maintained with sufficient structural integrity to prevent massive failure of the dikes."[1] The *Permit Applicant's Guidance Manual for Hazardous Waste Land Treatment, Storage, and Disposal Facilities* provides guidance on how to achieve the part 264 standard. The computer program that was developed in this study addresses most items covered by the above manual.

2.2 Permit Reviewers' Methods and Needs

An evaluation of the permit reviewers' methods and needs was undertaken in order to identify the analysis steps to be included in the computer program. Telephone conversations were held with selected permit reviewers in Ohio, Georgia, and New York. The EPA manual entitled "An Engineering Manual for the Evaluation of Dike Stability" (1983) and the final draft of the EPA guidance manual entitled "Permit Applicant's Guidance Manual for Hazardous Waste Land Treatment, Storage, and Disposal Facilities" (1984) were studied.

The evaluation demonstrated that reviewers typically had varied backgrounds and some had less than a comprehensive knowledge of geotechnical engineering. Also, many had only limited experience with computers, although at least half of the reviewers presently have access to an IBM personal comcomputer.

During the evaluation of methods and needs it was learned that the reviewer would first verify that a registered geotechnical engineer was employed to design the essential parts of the dike system. The reviewer is then required to verify the structural integrity of the dike system and, therefore, in checklist fashion should determine:

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[1] Federal Register, Volume 47, No. 143, Page 32274, July 26, 1982.

- the adequacy of the subsurface exploration program
- information on foundation conditions, quality of laboratory test data (especially on soil shear strength)
- liquefaction potential of the soils in the dike and the foundation
- the expected behavior of the dike when subjected to seismic effects
- the adequacy of the stability of the dike slopes and foundation soils
- potential for seepage-induced piping failure
- differential settlements in the dike

Based on the above criteria, general objectives for the computer program were established. The primary objective was that the program and all associated subroutines or blocks should be "user-friendly" and interactive, taking a simplified approach in explaining the data required for the analyses and the method used to enter the data into the computer program. Moreover, the program should be efficient, should have internal data check capabilities, and should have "user-friendly" error diagnostic features.

2.3 Program Search

A program search was conducted for adaptable computer programs which were available in the public domain.

The factors considered in the program search were: the general availability of the programs, the extent of documentation, initial costs, licensing requirements, and the language in which the programs were written.

The documentation would preferably include a flow chart, a dictionary of variables, comment statements in the listing, and a well-written user's manual. Since the GARDS program was to be developed for the IBM-PC/XT and PC/AT computers, ideally the programs to be adapted should also be written in IBM BASIC. Licensing requirements were especially important in that many sellers limit the use of a program tape or disk to one user and thus would prohibit its distribution to regional or state EPA offices. The adaptation of such a program would not be feasible.

Sources of programs included those programs known from various surveys and by reputation, those available in the Civil and Environmental Engineering

Department at the University of Cincinnati, and software advertisements. The majority of programs identified could only be used through licensing agreements and could not be freely distributed to EPA reviewers. Also, many programs could not practically be altered into a "user-friendly" format because of a lack of documentation and access to the computer code. Other programs were found to be relatively inefficient.

After an extensive software search, it was concluded that no programs which were ideal in all respects existed in the public domain. Two available programs which were judged to meet the technical requirements and which were sufficiently compatible were REAME (Rotational Equilibrium Analysis of Multilayered Embankments; Y. H. Huang, University of Kentucky) and SEEP (hydraulics analysis: K.S. Wong and J.M. Duncan, Virginia Polytechnic Institute). REAME was selected as a base program to which SEEP and all other GARDS program blocks (developed in-house) were adapted.

The GARDS software package addresses the basic need for hydraulic, slope stability, settlement and liquefaction analysis, including seismic effects. GARDS does not address the adequacy of the site subsurface exploration program, nor can it be used to gauge the quality of laboratory test data (section 2.2). In all cases, it is assumed that input parameters are selected with professional engineering judgment, and that they accurately reflect site conditions.

2.4 GARDS Features

The GARDS software package consists of several distinct blocks. Each block is a program in itself and is called by the user through the use of menu displays. The main command structure of the GARDS program is as follows:

1. Control Block
2. Input Block
3. Input Data Check and Edit Block
4. Hydraulics Analysis Block
5. Slope Stability Analysis Block
6. Settlement Analysis Block
7. Liquefaction Analysis Block
8. Summary Output Block

The following paragraphs present a brief description of each of the major program blocks.

2.4.1 Control Block

The control block is the first block encountered by the user. It gives an introduction to the program and other program blocks. Its primary function is to call the appropriate analysis block selected by the user from a "command menu" displayed on the screen. The menu is a list of the input/output and analytical options available to the user.

2.4.2 The Input Block

The input block is the first block to be selected by the user, and offers three user-friendly options:

1. Initial data entry with text explanations and graphical examples
2. Initial data entry without text explanations
3. Data entry using an existing data file

The first input option is designed to guide the occasional user through the initial data entry procedure. Explanations and graphical examples of the types of required input data are displayed on the screen prior to data entry. The option to review any or all explanations prior to data entry is available to enable the user to proceed at his own pace.

The second input option contains all of the features of option one, except that the text explanations and graphical examples are not included. This option would be selected for initial data entry by the user who is experienced in the use of GARDS and is therefore familiar with the definitions of the required input data.

The third option is selected by the user who has previously entered all data using options 1 or 2, has saved it on a data file, and elects to use the analysis features of the program at a later time. A listing of the data files available to the user is displayed. The data is assigned to the appropriate program variables internally. The use of this option eliminates the repeated entry of basic soil property and geometric data if the user wishes to re-analyze a particular dike Section under different conditions.

An internal data check is performed automatically with all input options to verify that values of all input variables fall within specified ranges. If the value of a data item is not within the specified range, an error message will prompt the user to enter a value within the specified range. Once notified, the user has the option to override this error trap routine if warranted.

2.4.3 Input Data Check and Edit Block

After having used one of the options of the input block, the input data check and edit block provides for general verification and modification of input data. The user may check or edit all or selected portions of the input data in any existing data file. Since, however, input and internally generated data routinely are output as part of the Summary Output Block (described later), the primary function of this block is to edit portions of existing data files in order to model different conditions for subsequent runs. This block is also routinely used to conduct a visual check of geometric continuity of the Section before proceeding with an analysis.

2.4.5 Hydraulics Block

The hydraulics block automatically determines the coordinates of the piezometric surface for any of six idealized hydraulic boundary conditions. The computations for the hydraulics block are made at the end of the input block so that the piezometric surface data is available for subsequent analyses. This block utilizes SEEP, a finite element based program for solving steady-state problems of free surface or confined flow of water in a two-dimensional porous region. A support program was developed to internally generate an input data file for SEEP from the general user-input data file. Another support program was developed to utilize the output from SEEP to determine the critical exit gradient and to relay the amount of seepage through the dike Section to the summary output block. The potential for failure of an impermeable barrier such as clay liner due to uplift pressure is also determined and noted in the summary output listing.

The six hydraulic boundary conditions comprise three typical unconfined steady state seepage conditions and three cases of confined seepage involving an impermeable barrier (clay liner) and excess pore pressure on the barrier. The six cases are illustrated in Figures 1 through 6 and are briefly described in the following paragraphs. The illustrations and narrative descriptions for each condition describe the internal analysis which is performed automatically within the hydraulics block. In all cases, a user defined piezometric surface is available as an option to model unusual hydraulic conditions.

Figure 1 illustrates the Deep Static hydraulic condition for the case of an existing or proposed dike with or without an adjacent excavation (landfill cell). In either case, the controlling criteria is that the groundwater table is everywhere at or below the existing or modified ground surface. As such, the condition does not represent a seepage case per se, and therefore does not involve rigorous hydraulic analysis (use of the SEEP program).

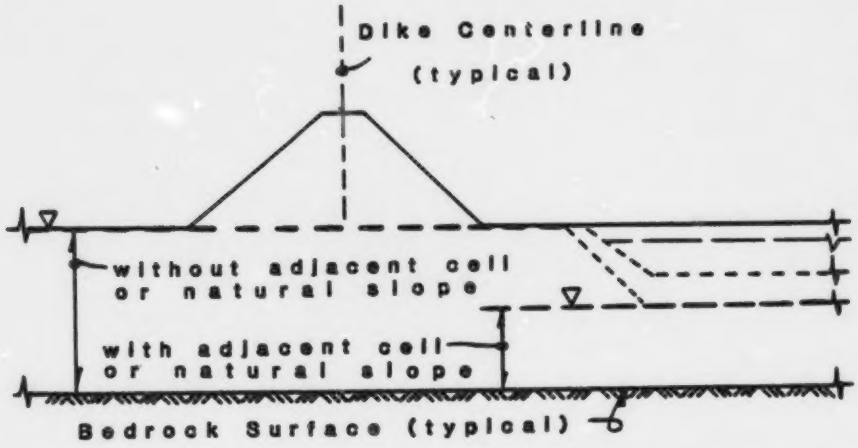


Figure 1. Range of Deep Static condition

The second hydraulic boundary condition involves shallow unconfined steady-state seepage which daylights on an adjacent natural or cut slope (into a landfill cell for example). Figure 2 illustrates the range of the Shallow Seepage condition. For this analysis, the piezometric surface is assumed to be coincident with the ground surface below the seepage daylight point on the slope. Since drawdown of the groundwater table in the vicinity of the daylight point is not assumed, a "worst case" slope condition is modeled.

The Free Pool Seepage condition illustrated in Figure 3 is the third unconfined seepage model. It is similar in principle to the Shallow Seepage case (Figure 2), but assumes a stationary upstream pool and development of steady-state free flow through the dike and into an adjacent excavation (if any). Using this hydraulic model, the user can investigate the stability of the dike under different pool conditions, with or without an adjacent excavation.

Figures 4, 5, and 6 represent the three confined seepage conditions involving the development of excess pore pressures within the slope and uplift pressure on the base on an impermeable confining layer (clay liner). In all cases, it is assumed that the stability of the Section under Shallow Seepage (Figure 2) or Free Pool Seepage conditions (Figure 3) is satisfactory (previously determined). A seepage analysis is performed within the SEEP subroutine to define the coordinates of the

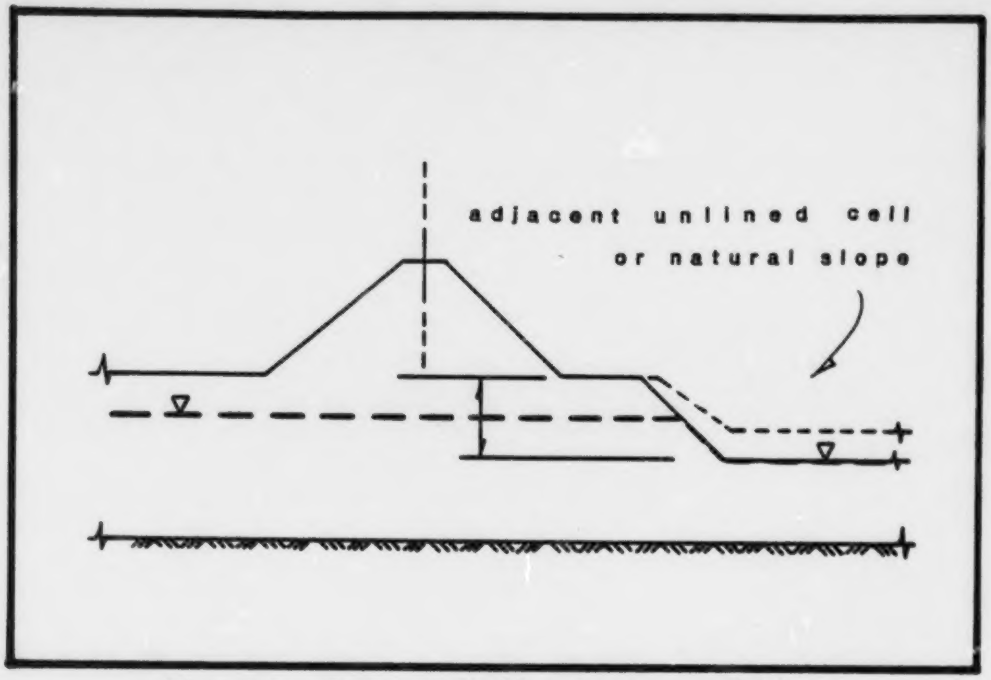

adjacent unlined cell
or natural slope

Figure 2: Range of Shallow Seepage condition

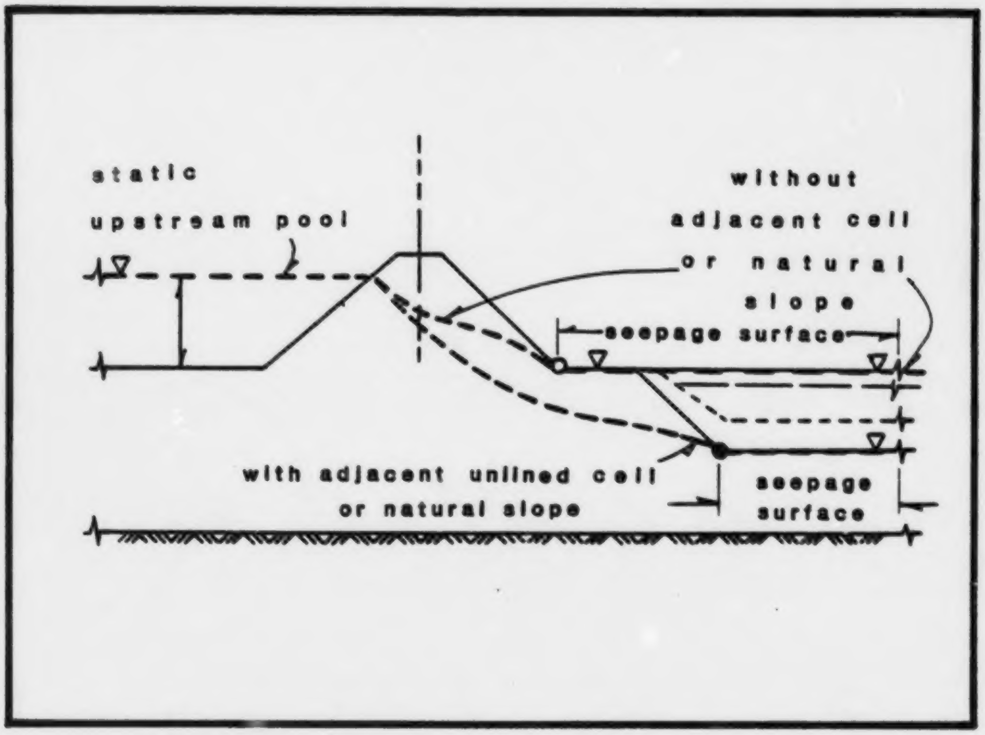

static
upstream pool
without
adjacent cell
or natural
slope
seepage surface
with adjacent unlined cell
or natural slope
seepage
surface

Figure 3. Range of Free Pool Seepage condition

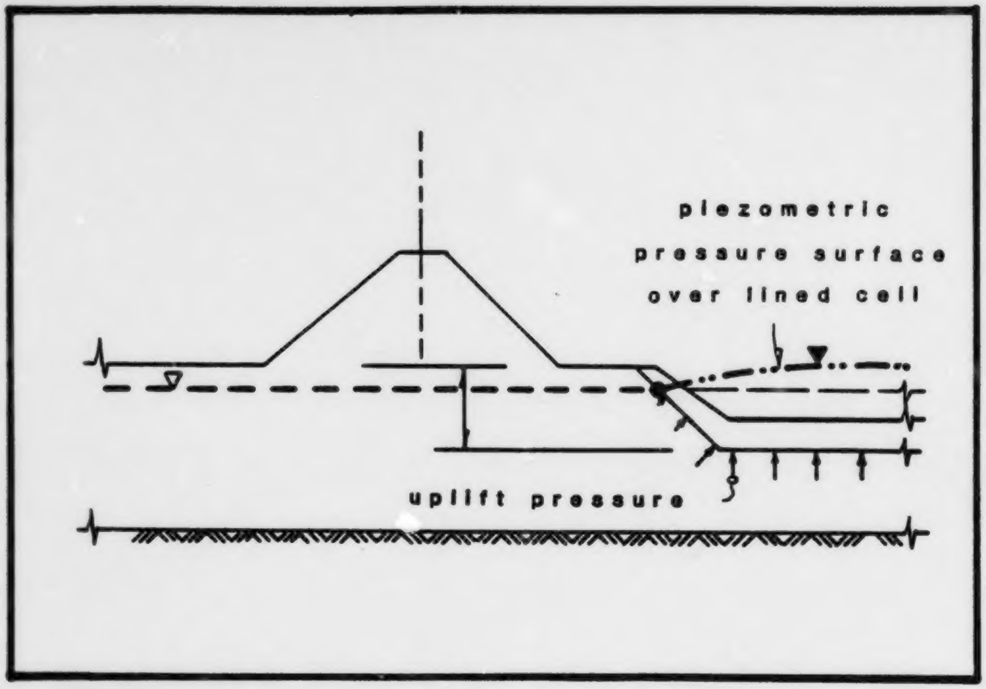

piezometric
pressure surface
over lined cell
uplift pressure

Figure 4. Range of the Shallow Confined Seepage condition

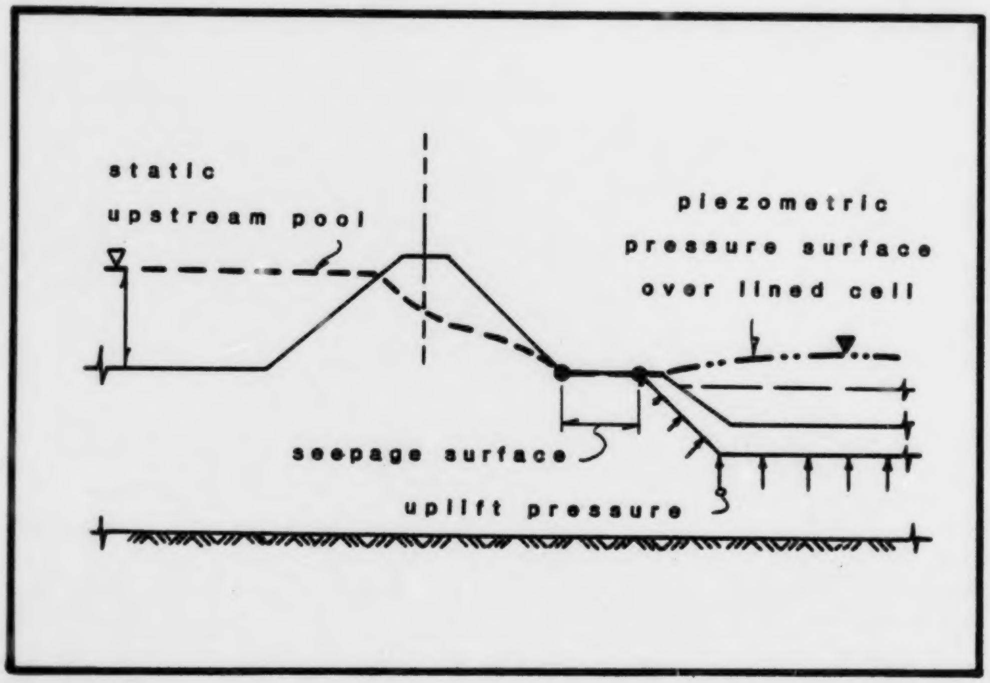

static
upstream pool
piezometric
pressure surface
over lined cell
seepage surface
uplift pressure

Figure 5. Range of Confined Pool Seepage condition

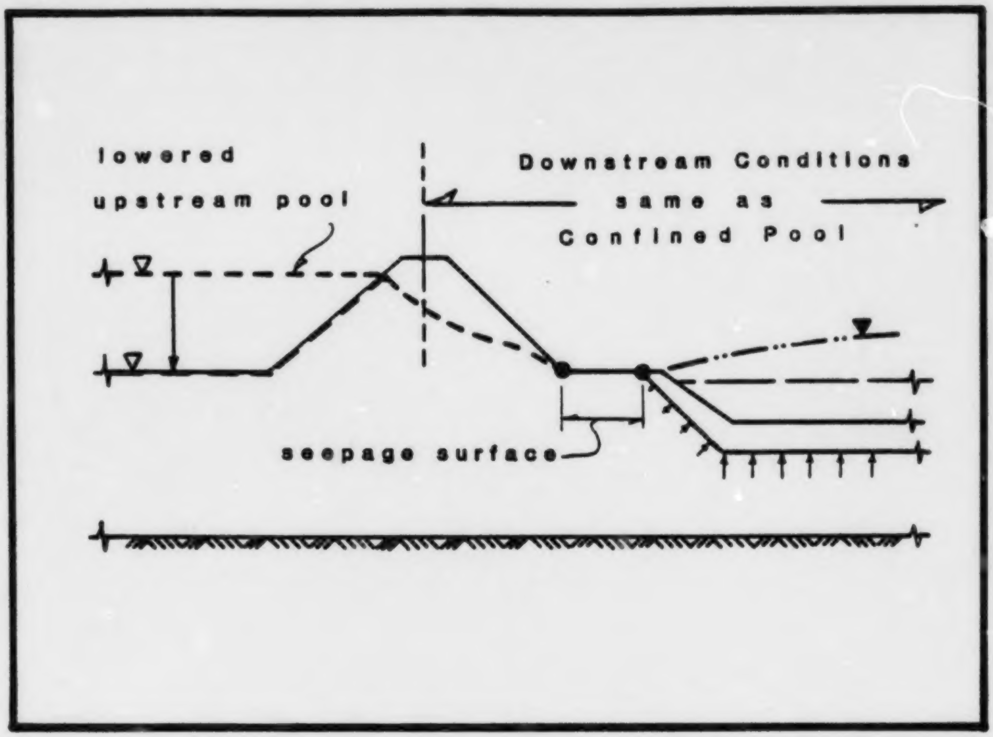


Figure 6. Range of Drawdown Pool condition

steady state piezometric surface through the Section. An uplift check is then performed within the Hydraulics Block to determine the adequacy of the liner either alone or with a waste surcharge. If results indicate that the liner is stable under the prevailing piezometric conditions, the user may then use the piezometric surface data for analysis of slope stabilty. If liner check results are unsatisfactory, slope stability analysis is considered irrelevant for the hydraulic conditions modeled.

The confined seepage boundary condition shown in Figure 6 is equivalent to the conventional "rapid drawdown" analysis on the upstream slope of a dike. The analysis assumes undrained slope conditions immediately after the abrupt drawdown of an adjacent pool which has existed long enough to establish a steady-state free flow surface through the dike. The SEEP program is used to compute the coordinates of the piezometric surface through the dike. Results are then automatically modified to reflect pool drawdown to the ground surface (as shown) before the hydraulics data are transferred to the slope stability block for stability analysis.

2.4.6 Slope Stability Analysis Block

The slope stability block uses data defining the piezometric surface from the Hydraulics Block to perform either of two conventional slope stability analyses. The first is a rotational (circular slip surface) analysis which uses the Simplified Bishop Method of slices. The second is a translational (plane slip surface) analysis based upon analysis procedures published in an engineering design manual developed by the U.S. Department of the Navy (NAVFAC DM-7.1, May 1982).

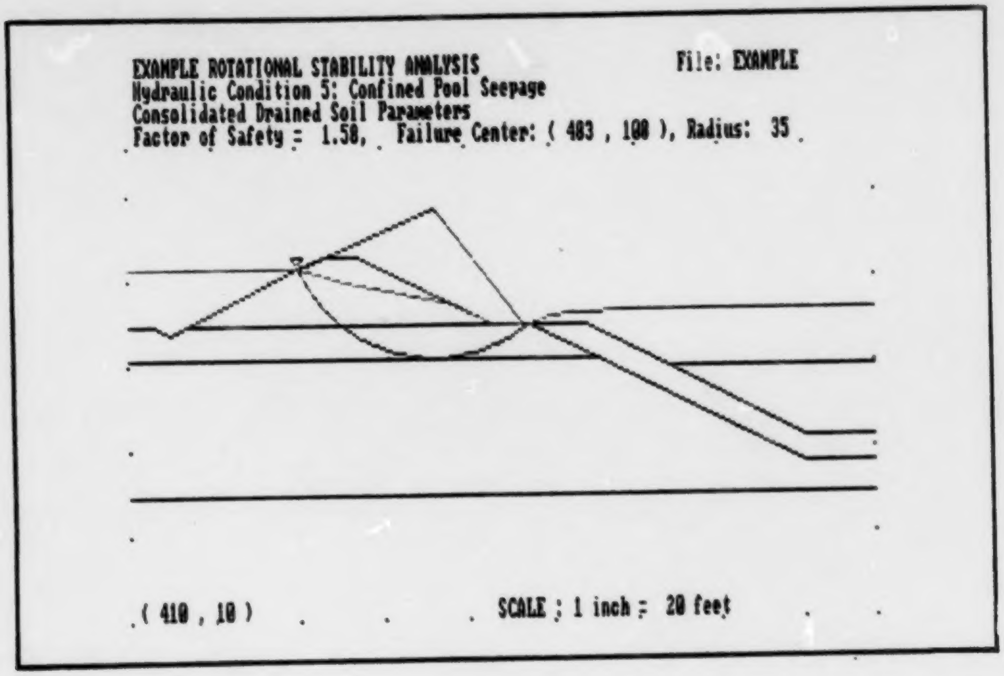
The major features of the Rotational analysis include:

- Dike slopes of any configuration and made up of up to 15 soil layers may be analyzed
- Seepage conditions are modeled in the form of the steady state piezometric surface through the Section as determined in the Hydraulics Block
- Seismic effects may be included
- The program has a radius control feature which produces trial circles that fall between specified limits defined by the soil layer geometry
- The program conducts an automatic search for the minimum factor of safety with trial arc centers specified by internally-generated or user-defined grids, or by user-specified centers

The major features of the Translational analysis option are the same as those for the rotational case except that the trial surface consists of straight line segments which form the base of one or more active (thrusting) wedges, a neutral or thrusting central block, and one or more passive (restraining) wedges. The automatic search routine for this analysis is based upon selection of a trial central block defined by the surface and subsurface soil layer geometry, followed by computation of the coordinates for the associated active and passive wedges. The analysis proceeds over all soil layers in the Section using a standard (automatic) or user-defined increment to define the location of subsequent trial central blocks.

Both stability analyses may be performed using any of the six hydraulic boundary conditions described earlier, and may employ unconsolidated-undrained (UU), consolidated-undrained (CU), or consolidated-drained (CD) soil strength parameters.

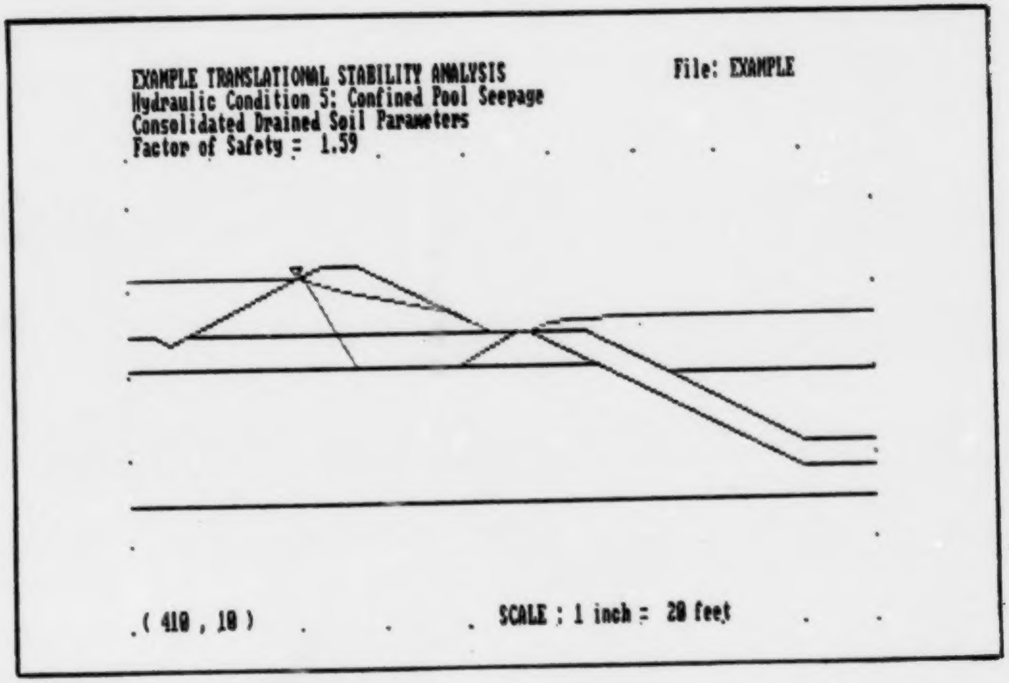
The results of the rotational analysis are presented as a tabulation of all factors of safety less than 2.5, along with the corresponding coordinates of the various failure arc centers, radii, and associated hydraulic boundary conditions. A plotting subroutine plots the dike Section, the most critical circle passing through it, the factor of safety, and other pertinent project information as shown in Figure 7.



```
EXAMPLE ROTATIONAL STABILITY ANALYSIS                    File: EXAMPLE
Hydraulic Condition 5: Confined Pool Seepage
Consolidated Drained Soil Parameters
Factor of Safety = 1.58,   Failure Center: ( 403 , 100 ), Radius: 35

( 410 , 10 )                 SCALE : 1 inch = 20 feet
```

Figure 7: Typical hard copy output for Rotational Stability Analysis



```
EXAMPLE TRANSLATIONAL STABILITY ANALYSIS                 File: EXAMPLE
Hydraulic Condition 5: Confined Pool Seepage
Consolidated Drained Soil Parameters
Factor of Safety = 1.59

( 410 , 10 )                 SCALE : 1 inch = 20 feet
```

Figure 8: Typical hard copy output for Translational Stability Analysis

The results of the Translational analysis are presented as the coordinates of the beginning and end points of the line segments representing the single most critical plane failure surface. A plotting subroutine plots the dike Section, the most critical plane failure surface, the factor of safety, and other pertinent project information as shown in Figure 8.

2.4.7 Settlement Analysis Block

The settlement analysis block is used to determine the compression of foundation soils due to stresses caused by the weight of an overlying dike. The settlements are calculated using Boussinesq's Theory and Terzaghi's One-Dimensional Consolidation Settlement Theorem. Required soil parameters for each soil include unit weight, initial void ratio, compression and recompression indices, and the overconsolidation ratio.

Settlements are calculated at the toes, crest points, and centerline of the dike. The consolidation of each soil is calculated for each layer and summed up for all soils to determine the total settlement at each point. Differential settlements are calculated between each toe and crest, toe and centerline, and crest and centerline on both sides of the dike.

2.4.8 Liquefaction Block

The liquefaction block determines the potential for liquefaction of the dike and foundation soils. The procedure used, developed by Seed and Idress (1983), applies mainly to site conditions involving sand or silty sand strata occuring below a level ground surface. The analysis uses soil parameters routinely obtained during site exploration and subsequent laboratory testing. Site seismic parameters may be estimated using published guidelines or may be obtained from site-specific investigation (preferred). The analysis uses an automatic search routine controlled by the Section geometry to locate the area of highest liquefaction potential. Results are reported as a tabulation of soil layers and points having a factor of safety which is less than or equal to 2.50.

2.4.9 Summary Output Block

The summary output block allows the user to obtain a hard copy of the input data and the results of all analyses run for the dike Section under study. The critical factors of safety, failure circle center coordinates, radius, and plane failure line segment coordinates are all highlighted in the output listing, along with the computed differential settlements, liquefaction potential, and critical exit gradient. If an analysis was not run, such is indicated in a summary table at the end of the output listing.

3.0 APPLICATION CONCEPTS

3.1 Procedural Overview

Although GARDS is designed to be flexible regarding the use and sequence of its various options, proper application requires that the user understand the function of each block, the relationship between the various blocks, and adhere to several basic procedural rules. The details of block function, relationship, and rules are covered in subsequent subsections. As an introduction, however, it is useful to describe the overall program structure and general sequence of use.

The GARDS command menu offers the following options:

*****GARDS Menu*****

(1) Initial Data Entry With Text Explanations
(2) Initial Data Entry Without Text Explanations
(3) Data Entry Using an Existing Data File
(4) Echo Check or Edit of Input Data
(5) Hydraulics Analysis
(6) Slope Stability Analysis
(7) Settlement Analysis
(8) Liquefaction Analysis
(9) Output Summary
(10) Save File or Quit

A routine session using GARDS involves the following general steps:

1. The user selects one of two primary input options from the main command menu (with or without text explanations)

2. Following input block prompts, the user names and builds a BASE data file which contains data describing site seismic parameters, the geometric configuration of the Section, and the properties of the various soils comprising the Section.

3. Following further input block prompts, the user specifies:

   - internal generation or manual input of the steady-state piezometric surface through the Section
   - one of six idealized hydraulic boundary conditions to be applied to the Section (internal generation option only; otherwise, the user inputs the coordinates of the final steady-state piezometric surface manually)
   - miscellaneous hydraulic parameters applicable to the hydraulic condition chosen
   - one of three available search scheme options for rotational slope stability analysis

4. After specification of the search scheme option, the hydraulic analysis is automatically performed before control is returned to the user (menu is displayed) for selection of a stability analysis option. Results of the hydraulic analysis are automatically added to the BASE data file.

5. The user calls up the slope stability analysis block and specifies either rotational or translational stability analysis and selects the soil strength parameters to be used (UU, CU, CD) in the analysis of the initial data file.

6. The user specifies an alternate soil strength parameter case to be evaluated (if appropriate).

7. The user again calls up the slope stability analysis block and specifies the analysis option (rotational or translational) not selected in step 6.

8. The user calls up additional analytical blocks (settlement or liquefaction) as may be allowed, depending upon the hydraulic boundary condition selected in step 3.

9. The user selects command menu option 10 (save file or quit) and saves the BASE data file along with the results from all analyses performed.

10. The user selects command menu option 9 (output summary) to generate hard-copy output of results.

Non-routine use of GARDS to evaluate alternate hydraulic conditions or subsequent Section configurations (staged construction) involves the following additional steps:

11. The user selects input option 3 (data entry using an existing data file).

12. The user copies the BASE data file previously saved in step 9. (Recall that the BASE data file contains the results of the initial hydraulic analysis.)

(13.) If the initial hydraulic analysis does not apply to the new case. The user selects option 5 (hydraulic analysis) and specifies the items listed in step 3, including a new hydraulic boundary condition to be analyzed. Results of the new hydraulic analysis are added to the BASE data file, replacing any and all results from previous hydraulic analysis.

NOTE: If the initial hydraulic analysis does apply to the new case, the user skips this step (new hydraulic analysis) and continues as follows:

(14.) The user then selects option 4 (Echo Check or Edit of Input Data) and changes the project identification and file name (to reflect the new case) along with the Section geometry (if necessary) to properly model conditions for stability. Changing the Section geometry might involve modification of an existing soil (raised dike, for example) or addition of a new soil (clay liner). In either case, changing the Section involves redefining soil boundary lines and boundary line point coordinates and the input of parameters for the new soil (if any).

15. The user repeats steps 5 through 10 as appropriate.

For complete analysis of a dike application involving multiple hydraulic boundary conditions and multiple changes in the Section geometry to represent staged construction, the user should repeatedly copy the BASE data file (steps 11, 12), followed by modification, analysis, and hard-copy output (steps 13 through 15)

Figures 9 and 10 are abbreviated summaries of the recommended sequence of menu options depending upon the data input option selected. These figures are provided as a summary reference source for the user.

RECOMMENDED MENU OPTION SEQUENCE: INPUT OPTIONS (1) OR (2)
(Initial data entry with or without text explanations)

STEP

1. Create (name) BASE data file and input Section parameters (1),(2); input pertinent information describing the Section characteristics and hydraulic boundary condition to be used under "Project Identification"

2. Specify method of determination of final steady-state piezometric surface

   - internal (automatic) → specify hydraulic boundary condition

   - manual

3. a. Check results and edit file if necessary (4)
   b. Rerun hydraulics analysis if file changed in step 3a (5)

4. Select slope stability analysis option, repeat as necessary

5. Select additional stability analysis options which are compatible with hydraulic boundary condition chosen (see Table 1)

6. Obtain hard copy summary output (9)

7. Save BASE data file plus results of all analyses performed (10)

8. Return to menu, continue per Figure 10, or QUIT (10)

Numbers in parentheses ( ) indicate menu option.

Figure 9

RECOMMENDED MENU OPTION SEQUENCE: INPUT OPTION (3)
(Data entry using an existing data file)

STEP

1. Input (copy) existing BASE data file (3)
2. Select hydraulic analysis (5)
3. Specify method of determination of final steady-state piezometric surface
    - internal (automatic) → specify hydraulic boundary condition
    - manual
4. a. Check hydraulic results and edit file (4)
   b. Repeat steps 2 - 4a if file is edited due to input error
5. Edit data file:
   a. input new information identifying the Section characteristics and hydraulic boundary condition used under "Project Identification"
   b. input new file name
   c. change Section parameters (new boundary lines, new soils, new soil properties) to model for Slope Stability Analysis (4)
6. Select Slope Stability Analysis (6)
7. Specify compatible stability analysis option other than Slope Stability (7) or (8) (see Table 1)
8. Obtain hard copy summary output (9)
9. Save re-named data file plus results of all analyses (10)
10. Return to menu, restart with step 1, or QUIT (10)

Numbers in parentheses ( ) indicate menu option.

Figure 10

3.2 The BASE Data File

Analysis for a typical dike application may involve analysis of different Sections using different hydraulic and soil parameters (staged construction). A BASE data file is a data file reserved for future use which contains the elements of Section geometry common to multiple analysis cases. A modified file is simply a BASE data file which has been retrieved (copied into the Input Block) and subsequently modified to model changed Section conditions such as an added soil layer or a different hydraulic boundary condition (different seepage case).

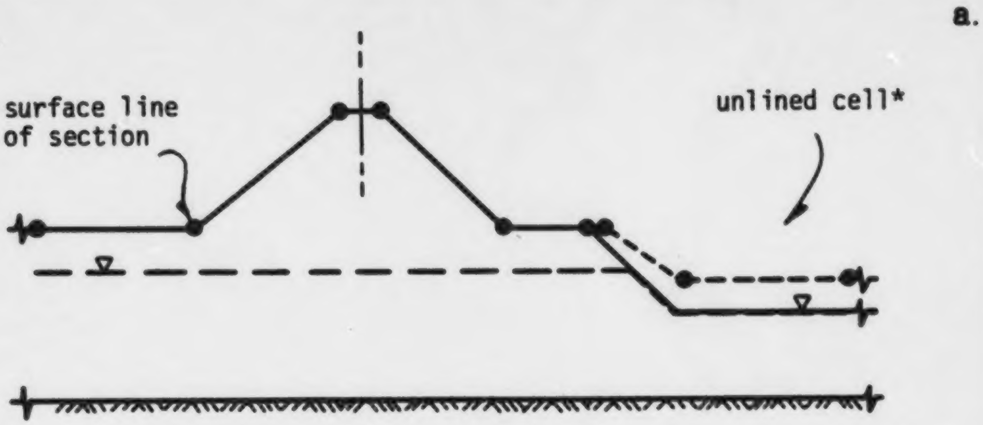
If, for example, the proposed construction sequence for a particular application involving a shallow groundwater table (piezometric surface) is:

- concurrent excavation for a landfill cell and construction of a perimeter dike
- liner construction within the cell
- on-going disposal of waste in the lined cell
- future potential for flood or a static pool on the upstream side of the dike

Then, the long-term or "final" site condition to be analyzed might appear as shown in Figure 11b. In this case, the BASE and initial data file would consist of geometric elements shown in Figure 11a. A modified data file for a given application is built up from the BASE data file and is therefore typically more complex than the BASE data file. In this example, other intermediate stages would have been developed and analyzed as modified files between the BASE and "final" modified cases shown.

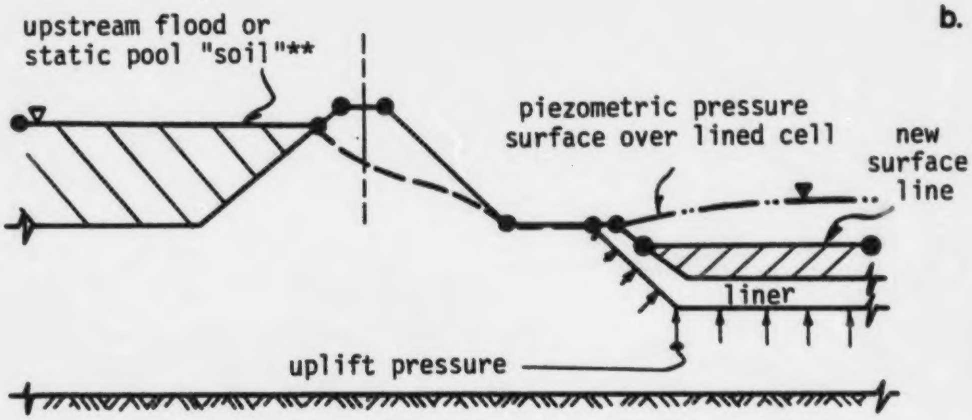
The rule that a BASE data file contains only the elements of Section geometry which are common to all cases has one exception. If the dike application involves or will involve a clay liner, the BASE and subsequent modified data files may contain the liner as a geometric element even though it may not apply to all hydraulic boundary conditions the user may wish to analyze. Where the liner does not apply (any general seepage condition which is analyzed prior to the construction of the liner), the user simply identifies the clay liner by soil number and the program automatically disregards the liner in the hydraulic analysis.

During the development of the hydraulics block, it became necessary to define the various hydraulic elements in a consistent manner. Accordingly, the convention used throughout GARDS is that a run-on pond, or a flood or static pool is located on the left (upstream) side of the dike, and the landfill cell, if any, is located on the right (downstream) side of the dike as shown in Figure 11b.


a.
surface line of section
unlined cell*

*Liner may be part of BASE data file, but is ignored in hydraulic analysis

GEOMETRIC ELEMENTS OF THE BASE DATA FILE


b.
upstream flood or static pool "soil"**
piezometric pressure surface over lined cell
new surface line
liner
uplift pressure

**See soil boundary line rules 10 and 16; section 4.3.4.1

GEOMETRIC ELEMENTS OF THE FINAL MODIFIED DATA FILE

Figure 11. Typical BASE and Modified Sections

3.3 Hydraulic Analysis of the BASE Data File

Hydraulic analysis is used to determine:

- the configuration of the steady-state piezometric surface through the Section

For Sections involving an upstream static or flood pool, hydraulic analysis also determines:

- seepage quantity
- critical (highest) exit gradient
- potential for uplift of a clay liner due to excess pore pressures produced by a confined seepage condition

Typically, the above analyses are performed prior to the use of one of the stability analysis options (slope stability, settlement, liquefaction). If the results for any of the above are unsatisfactory, further stability analysis generally is considered to be irrelevant.

Within the hydraulics block, the user is given two options:

1. Steady-state piezometric surface determined automatically, based on one of six pre-programmed idealized hydraulic boundary conditions

2. Steady-state piezometric surface defined by the user and input manually as point coordinate data (no hydraulic 'analysis' actually performed; user assumes a final steady-state configuration)

A major limitation of the second (manual input) option is that the determination of seepage quantity, critical exit gradient, and liner uplift potential is not performed. It may be used only as a means of evaluating the effects of non-standard piezometric configurations on the stability of the Section. It exists primarily for use by qualified geotechnics professionals and should not be used without technical justification.

The Hydraulics Block may be accessed in one of two ways. If the user selects input options 1 or 2 from the command menu (with and without text explanations, respectively), the Hydraulics Block is automatically called up and executed at the end of the data input operation. If the user selects input option 3 (data entry using an existing data file), the Hydraulics Block must be called up directly from the command menu. In either case, the user is given the option to select either automatic generation of the piezometric surface for one of the six idealized hydraulic boundary conditions, or manual input of a user-defined piezometric surface. In all cases, results of the hydraulic analysis are added to the data file, replacing any previous hydraulics results. A cautionary statement appears at the beginning of the Hydraulic Block to warn the user that a new hydraulics analysis will result in the loss of any previous hydraulics results which may be in the file being used. Figure 12 is a general flow chart illustrating the control relationships between the Hydraulics Block and the various input options. The six idealized hydraulic boundary conditions which may be analyzed automatically within the Hydraulics Block comprise three typical unconfined steady-state seepage conditions (Nos. 1, 2, 3) and three cases of confined seepage involving an impermeable barrier (clay liner) and excess pore pressure beneath the barrier (Nos. 4, 5, 6).

In the general case, the user simply selects the boundary condition which applies to the Section model being analyzed and inputs miscellaneous additional information as prompted, depending upon the condition selected.

Figures 13 through 18 detail the criteria, additional input requirements, and limitations for each hydraulic boundary condition. These figures are provided as a summary reference source defining the primary requirements of the BASE data file for each hydraulic boundary condition. In each case, output comprising the X-Y coordinates of the final steady-state piezometric surface are generated on hard copy and automatically added to the data file.

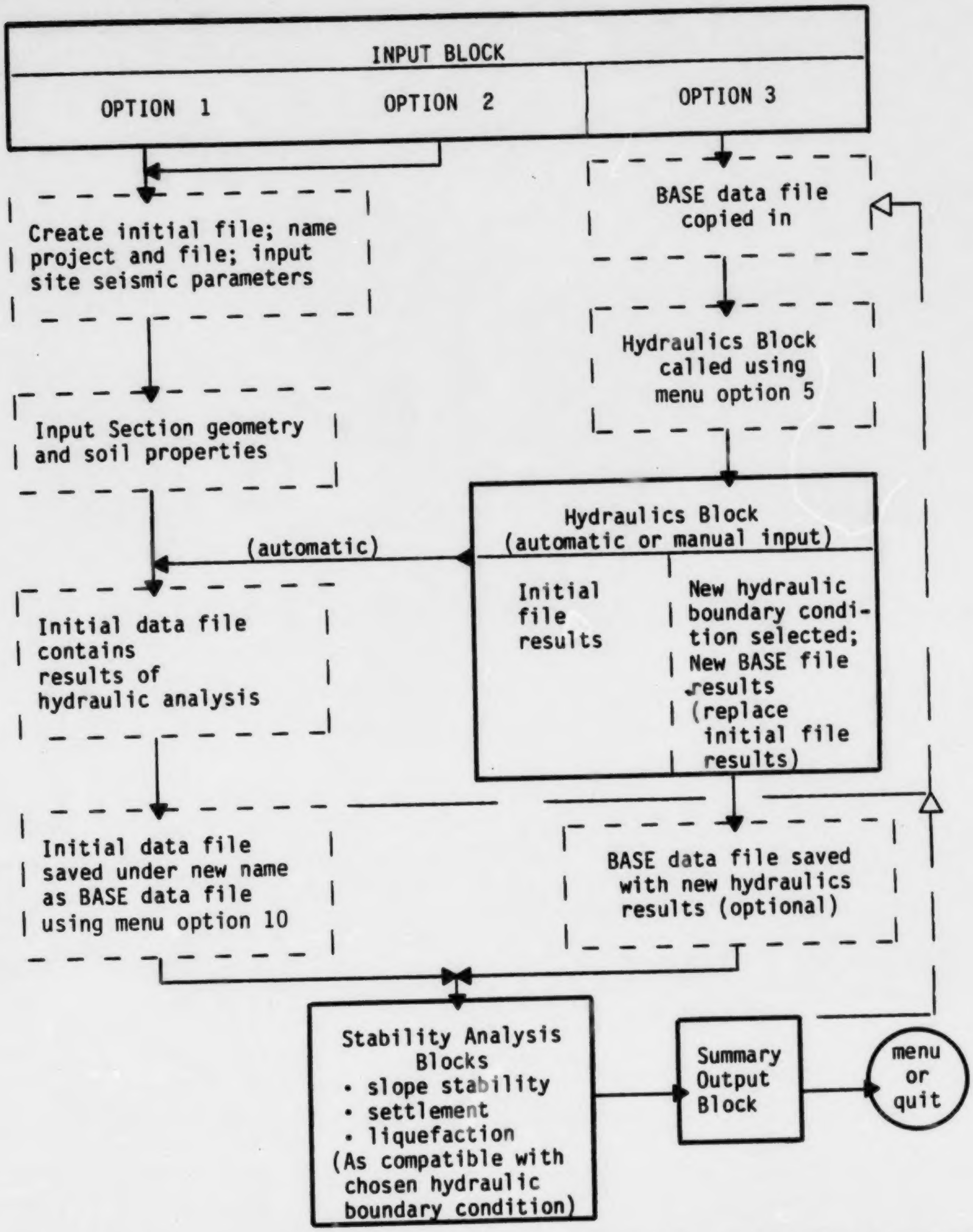
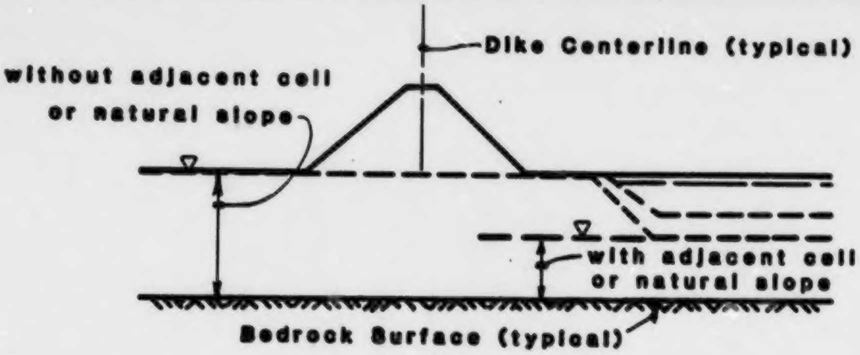

INPUT BLOCK
OPTION 1
OPTION 2
OPTION 3
Create initial file; name project and file; input site seismic parameters
Input Section geometry and soil properties
(automatic)
Initial data file contains results of hydraulic analysis
Initial data file saved under new name as BASE data file using menu option 10
BASE data file copied in
Hydraulics Block called using menu option 5
Hydraulics Block (automatic or manual input)
Initial file results
New hydraulic boundary condition selected; New BASE file results (replace initial file results)
BASE data file saved with new hydraulics results (optional)
Stability Analysis Blocks
• slope stability
• settlement
• liquefaction
(As compatible with chosen hydraulic boundary condition)
Summary Output Block
menu or quit

Figure 12. Flow chart of Input and Hydraulics Block control relationship

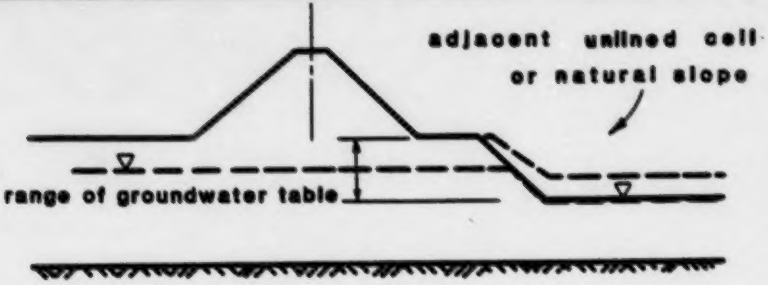
1


Dike Centerline (typical)
without adjacent cell
or natural slope
with adjacent cell
or natural slope
Bedrock Surface (typical)

CRITERIA	Piezometric surface (groundwater table) is everywhere at or below the ground surface of the Section; seepage does not daylight anywhere in the Section
ALTERNATE SECTIONS	• Dike without adjacent cell • Dike with adjacent unlined cell or natural slope • Dike with adjacent lined cell • Dike with adjacent lined cell plus waste surcharge
SPECIAL INPUT	Seasonal high groundwater table elevation (if any)
SPECIAL FEATURES	None
LIMITATIONS	None

Figure 13. Deep Static Condition

2

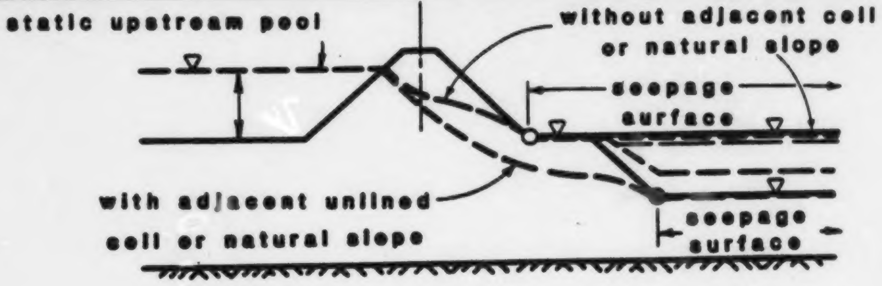


CRITERIA	• Seepage (piezometric surface) daylights on an adjacent natural or cut slope (into a landfill cell, for example)
ALTERNATE SECTIONS	• Dike with adjacent natural slope or unlined cell • Dike with adjacent lined cell*
SPECIAL INPUT	• Seasonal high groundwater table elevation • The number of the soil representing the clay liner, "0" if none
SPECIAL FEATURES	• Clay liner (if any) ignored in hydraulics analysis to model unconfined free seepage flow* • Seepage line automatically modified to coincide with ground surface below seepage daylight point on slope
LIMITATIONS	• No liner uplift check since liner is ignored (use Shallow Confined Seepage case) • Seepage quantity and exit gradient not determined

*liner may be part of BASE data file, but is ignored in hydraulic analysis

Figure 14. Shallow Seepage Condition

3

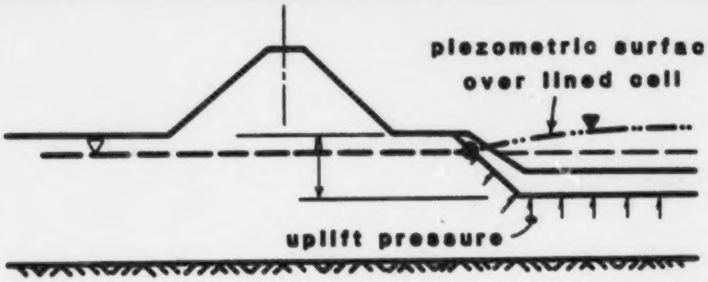

static upstream pool
without adjacent cell
or natural slope
seepage
surface
with adjacent unlined
cell or natural slope
seepage
surface

CRITERIA	• Static upstream pool has existed long enough to establish steady-state free flow through the Section
ALTERNATE SECTIONS	Upstream static or flood pool • without cell adjacent to dike • with unlined cell adjacent to dike • with lined empty cell adjacent to dike*
SPECIAL INPUT	• Elevation of the upstream static or flood pool • The number of the soil representing the clay liner; '0' if none
SPECIAL FEATURES	• Clay liner (if any) ignored in hydraulics analysis to model unconfined free seepage flow* • Seepage line automatically modified to coincide with ground surface below seepage daylight point (○,●) in the Section • Maximum exit gradient on seepage surface computed • Total seepage discharge determined over seepage surface
LIMITATIONS	• No liner uplift check since liner is ignored (use Confined Pool seepage case) • Seepage daylight point assumed to be at base of excavated slope (●) or base of dike if an excavation is not present (○) • Settlement analysis may not be performed on Sections analyzed under this condition • Hydraulic conductivity (permeability) of soils in the Section may not vary by a factor of more than 100

*liner may be part of BASE data file, but is ignored in hydraulics analysis

Figure 15. Free Pool Seepage Condition

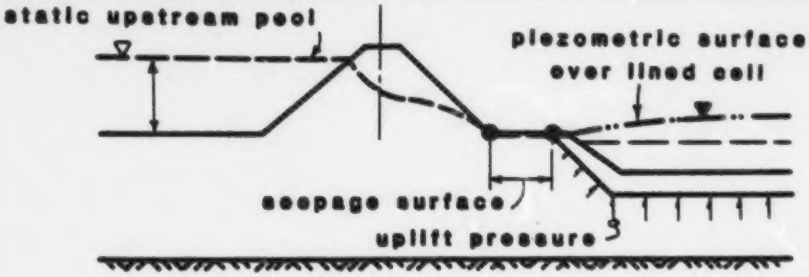
4



CRITERIA	Shallow piezometric surface intersects a liner above the base of the cell producing confined seepage flow along the base of the liner and excess pore pressure (uplift) on the liner
ALTERNATE SECTIONS	• Dike with adjacent lined cell • Dike with adjacent lined cell plus waste surcharge
SPECIAL INPUT	• Seasonal high groundwater table elevation • Elevation of the top of the waste layer (if any) in the cell • The number of the soil representing the clay liner
SPECIAL FEATURES	• Seepage line automatically modified to coincide with the base of the liner below its point of intersection with the shallow piezometric surface (●) • Liner uplift check performed automatically based upon the elevation of the piezometric surface over the cell and the thickness of the liner and waste surcharge (if any) • Results of liner uplift check automatically added to data file NOTE: If liner is inadequate, stability analysis may still be performed, but is considered to be irrelevant
LIMITATIONS	• Hydraulic conductivity (permeability) of soils in the Section other than the liner and waste (if any) may not vary by a factor of more than 100

Figure 16. Shallow Confined Seepage Condition

5



CRITERIA	• Static upstream pool has existed long enough to establish steady-state free flow through the dike, seepage daylighting between the downstream toe of the dike and a clay liner, and confined seepage flow along the base of the liner, producing excess pore pressure (uplift) on the liner
ALTERNATE SECTIONS	Upstream static or flood pool: • with lined cell adjacent to dike • with lined cell and waste surcharge adjacent to dike
SPECIAL INPUT	• Elevation of the upstream static or flood pool • Elevation of the top of the waste layer in the cell (if any) • The number of the soil representing the clay liner
SPECIAL FEATURES	• Seepage line automatically modified to coincide with base of liner • Liner uplift check performed automatically based upon the elevation of the piezometric surface over the cell and the thickness of the liner and waste surcharge • Results of liner uplift check automatically added to data file Note: If liner is inadequate, stability analysis may still be performed, but is considered to be irrelevant. • Maximum exit gradient on seepage surface computed • Total seepage discharge determined over seepage surface

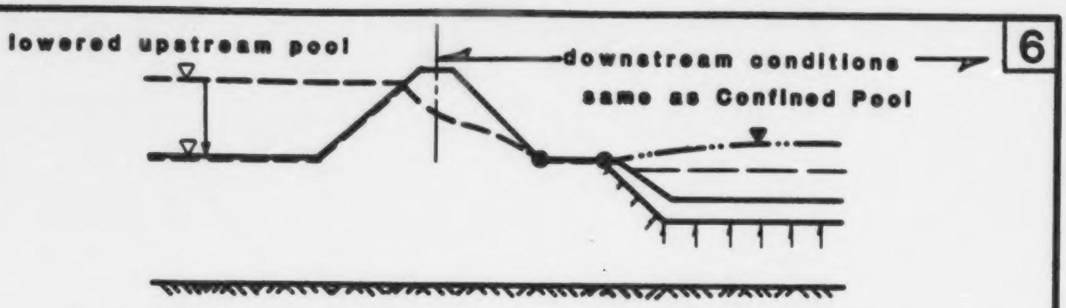
(CONTINUED)

Figure 17. Confined Pool Seepage Condition

CONFINED POOL SEEPAGE CONDITION (Cont.)

LIMITATIONS

- Top of liner and downstream toe of dike must be at the same elevation
- Settlement analysis may not be performed
- Hydraulic conductivity (permeability) of soils in the Section other than the liner and waste (if any) may not vary by a factor of more than 100



CRITERIA

- Upstream static or flood pool for Confined Pool seepage condition (see Figure 17) is abruptly lowered to coincide with the ground surface on the upstream side of the dike

ALTERNATE SECTIONS

Upstream static or flood pool
- with lined cell adjacent to dike
- with lined cell and waste surcharge adjacent to dike (same as Confined Pool seepage condition)

SPECIAL INPUT

- Elevation of the upstream static or flood pool
- Elevation of the top of the waste layer (if any)
- The number of the soil representing the clay liner

SPECIAL FEATURES

- Seepage line automatically modified to coincide with base of liner
- Liner uplift check performed automatically based upon the elevation of the piezometric surface over the cell and the thickness of the liner and waste surcharge
- Results of liner uplift check automatically added to data file

> Note: If liner is inadequate, stability analysis may still be performed, but is considered to be irrelevant.

- Maximum exit gradient on seepage surface computed
- Total seepage discharge determined over seepage surface

(CONTINUED)

Figure 18. Drawdown Pool Condition

DRAWDOWN POOL CONDITION (Cont.)

LIMITATIONS

- Top of liner and downstream toe of dike must be at the same elevation
- Settlement analysis may not be performed
- Hydraulic conductivity (permeability) of soils in the Section other than the liner and waste (if any) may not vary by a factor of more than 100
- May not be used for the stability analysis of the general Confined Pool seepage condition, although exit gradient, seepage quantity, and liner uplift results are equivalent to those generated using the Confined Pool seepage condition on equivalent Sections having equivalent static or flood pool elevations

3.4 Compatible Analysis Options

The job of the project geotechnical engineer is to identify the various site conditions which need to be investigated and to select the appropriate combination of options which best models those conditions. GARDS offers the user six idealized hydraulic boundary conditions, three stability options (slope stability, settlement, liquefaction), and three soil strength options (UU, CU, CD). A limited amount of guidance logic has been built into GARDS to assist the non-specialist user in making decisions regarding the available analysis options.

For example, it is not possible to perform a settlement analysis on a Section having an upstream pool (hydraulic boundary conditions Nos. 4, 5, 6). The premise is that settlement will occur in connection with new dike construction and that all settlement due to the weight of the dike should be permitted to occur before a pool is established on the upstream side of the dike. The pool therefore generally represents a long-term condition after consolidation of the dike foundation has taken place.

Also, it is not possible to perform a slope stability analysis using a non-zero seismic coefficient with UU or CU soil strength parameters. The premise in this case is that the use of UU or CU parameters represents a short-term, temporary condition (end of construction or drawdown pool, for example) and that the probability of seismic activity occurring during the temporary condition is acceptably small. Moreover, the use of UU or CU strength parameters in combination with seismic effects would often result in significant overdesign of the Section for the long-term (CD parameter) case. Seismic slope stability analysis in GARDS is therefore limited to cases involving CD strength parameters. (The user may circumvent this limitation, however, simply by making the CD strength parameters in the input file equal to the UU or CD parameters, which do not usually apply. Such action may lead to confusion, however, and should not be taken without clear technical justification).

Table 1 lists the compatible analysis options available for normal use of GARDS.

TABLE 1. COMPATIBLE ANALYSIS OPTIONS

STABILITY ANALYSIS	COMPATIBLE HYDRAULIC BOUNDARY CONDITION	COMPATIBLE SOIL STRENGTH CONDITION
Slope stability without seismic coefficient	All idealized conditions 1 through 6 plus user-defined piezometric surface	UU, CU, CD as appropriate
Slope stability with seismic coefficient	All idealized conditions 1 through 6 plus user-defined piezometric surface	CD; any long-term condition
Settlement analysis	All idealized conditions except Pool conditions (Free Pool, Confined Pool, Drawdown Pool) plus user-defined non-pool piezometric surface	UU, CU, CD as appropriate (settlement controlled by other soil parameters; see Table 3)
Liquefaction analysis	All idealized conditions except 6 (Drawdown Pool), plus user-defined piezometric surface	CD; any long-term condition

3.5 Rotational Slope Stability Analysis (REAME)

3.5.1 General

Rotational slope stability analysis is performed using the Simplified Bishop method of slices. For each trial arc, the Section is subdivided into vertical slices (minimum of 10, maximum of 40), each having its base coincident with a portion of the trial arc. Slices are defined according to the Section geometry such that the base of each slice comprises only one soil type. The effective weight and soil shear strength along the base of each slice is then computed and used to compute overturning (driving) and resisting moments about the center of rotation. The overturning and resisting moments are then summed and the Factor of Safety is computed as:

$$F = \frac{\sum_{i=1}^{n} \frac{\bar{c} b_i + b_i(\gamma h_i - \gamma_w h_{iw}) \tan \bar{\phi}}{\cos \theta_i + (\sin \theta_i \tan \bar{\phi})/F}}{\sum_{i=1}^{n} (W_i \sin \theta_i + C_s W_i a_i / R)}$$

where:

$\overline{c}$ is the effective cohesion of the soil at the base of the slice
$\overline{\phi}$ is the effective friction angle of the soil at the base of each slice
b is slice width
h is the distance from the failure surface to the piezometric surface for each slice
θ is the angle between the base of the slice and the horizontal
W is the total weight of each slice
C_s is the seismic coefficient
a is the moment arm for each slice
R is the radius of the trial arc

The trial arcs which are tested for each Section are determined automatically by the search scheme selected by the user (section 3.5.2) and the radius control zones automatically generated for the Section (section 3.5.3).

As modified for use in GARDS, REAME will evaluate slope stability based upon either an internally generated piezometric surface for one of six idealized hydraulic boundary conditions, or a piezometric surface defined by the user. In either case, the piezometric surface is independent of soil boundary lines and may be located above or below the surface line of the Section. Where a body of water exists, however, the water surface is a segment of the piezometric surface and also a segment of the surface line of the Section. When a trial arc cuts through a standing body of water, the weight of the body of water above the surface is ignored, but the horizontal water pressure on the sliding mass is used in determining the overturning moment.

3.5.2 Search Schemes

Search schemes are used in the rotational slope stability analysis to locate the center of the failure circle having the minimum factor of safety for the slope conditions under study. There are three search schemes available:

1) Internally generated grid search (automatic search)
2) User-defined grid search
3) User-defined point search

In general a grid is established over the slope as illustrated in Figure 19a. This grid can be established automatically as a function of slope geometry or by the user in defining the limits of the grid (points

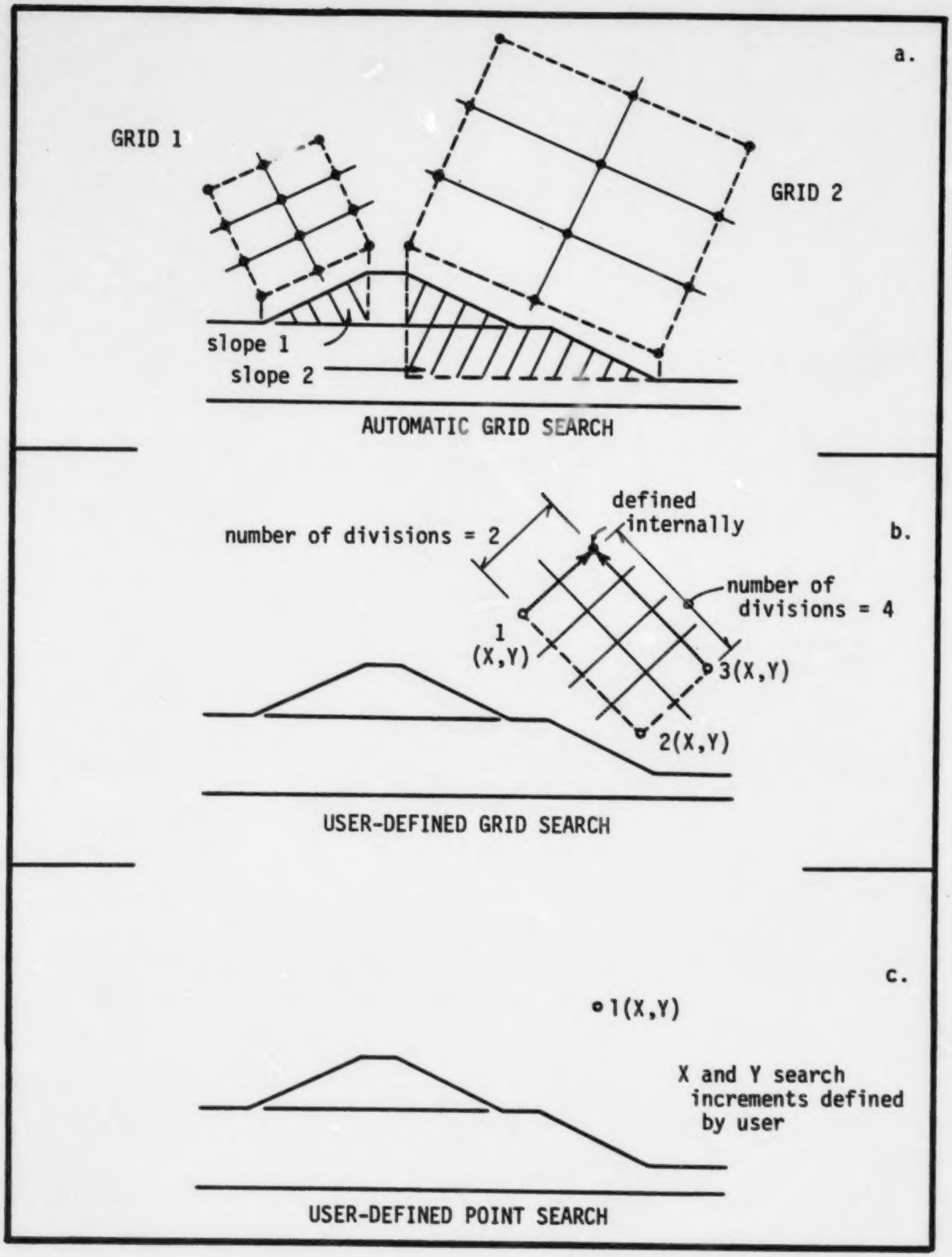

a.
GRID 1
GRID 2
slope 1
slope 2
AUTOMATIC GRID SEARCH
b.
number of divisions = 2
defined internally
number of divisions = 4
1 (X,Y)
3(X,Y)
2(X,Y)
USER-DEFINED GRID SEARCH
c.
1(X,Y)
X and Y search increments defined by user
USER-DEFINED POINT SEARCH

Figure 19: Search scheme options for rotational slope stability analysis

1, 2, and 3, Figure 19b) and specifying the number of divisions between points 1, 2, 3.

For a typical internal or user-defined grid, the program computes the slope stability factor of safety at each grid point, using circle radii internally specified by the number of radius control zones (see section 3.5.3). After results from all grid points have been obtained, the program conducts a local search around the grid point having the lowest factor of safety. The following information summarizes the pertinent features of the three search scheme options.

3.5.2.1 Internally Generated Grid Search (Figure 19a)

A grid search can be generated internally based upon the Section geometry. This internally generated grid covers an area large enough that the minimum factor of safety may reasonably be expected to be found.

If the user defines his own grid for the search, he must be careful to cover all areas in which a critical circle may exist.

3.5.2.2 User-Defined Grid Search (Figure 19b)

This search scheme allows the user to specify a parallelogram grid to determine the minimum factor of safety for a set of failure arc centers. The parallelogram grid is defined by the following parameters:

- the X-coordinate of the grid boundary points 1, 2, and 3
- the Y-coordinate of the grid boundary points 1, 2, and 3
- the number of divisions between points 1 and 2
- the number of divisions between points 2 and 3

The three grid boundary points form the two adjacent sides of of a parallelogram.

A point search or "local" search is conducted after the general grid search. The point of minimum factor of safety determined in the grid search is used as the center (starting point) for the point search.

3.5.2.3 User-Defined Point Search (Figure 19c)

The user-defined point search is a search conducted around a trial center to determine the local minimum factor of safety. The point search proceeds along an X-axis and along a Y-axis, with the trial center used as the origin.

When the user-defined point search is used alone, without the grid search, the X-coordinate and the Y-coordinate of the trial center and the X and Y search increments must be defined by the user.

The point search is conducted as follows:

1) The factor of safety at the trial center is determined
2) Proceeding to the right, point 2 is located at a distance equal to the indicated X increment
3) If the factor of safety at point 2 is less than that at point 1, the search will continue to the right with steps equal to the X increment until the factor of safety at some point becomes greater than that at the previous point
4) The search will then go back to the trial center
5) Proceeding to the left with steps equal to the X increment, calculate the factors of safety until one is found that is greater than that for the previous point
6) Use the grid point at which the minimum factor of safety in the X direction was found as the next starting point
7) Proceeding upward with steps equal to the Y increment, calculate factors of safety until one is found that is greater than that for the previous point
8) The search then goes back to the starting point found in step 6 and proceeding downward with steps equal to the Y increment, calculates factors of safety until one is found that is greater than that for the previous point
9) Having found the grid point with the minimum factor of direction, proceed to the right and to the left to find the minimum factor of safety in the horizontal direction
10) This is the minimum factor of safety based on full X and Y increments
11) Use the point with the minimum factor of safety based on full X and Y increments as the next starting point
12) Repeat the search process using one-fourth of the X and Y increments as the new increments for the search

13) The search proceeds alternately in the horizontal and vertical direction until a factor of safety smaller than the surrounding four points is obtained

3.5.3 Radius Control Zones

The search scheme specification procedure described in the preceding section constitutes half of the information required to define the number of trial failure arcs to be analyzed for a given case. One must also specify the radius of a trial arc to be used at each grid point. This is accomplished internally using a predefined number of radius control zones.

Each soil is designated as a radius control zone. At each grid point, a minimum of three trial radii defined by the perpendicular distance to the base, midpoint, and top of each zone (soil) are tested. Within each zone (soil), the resulting factor of safety for each trial radius is stored for comparative purposes.

If the result for the trial arc through the midpoint of the zone (soil) is a relative minimum, one additional arc is tested between the middle arc and each of the zone (soil) boundaries (total of five trial arcs for the zone [soil] for each grid point).

If the result for either trial arc tangent to the top or bottom of the zone (soil) is the relative minimum, one additional trial arc between the midpoint and that boundary representing the relative minimum is tested (total of four trial arcs for the zone [soil] for each grid point).

The above search routine is performed for each trial center grid point and for the point search around the grid point having the lowest result. The minimum number of trial arcs for a complete rotational stability analysis involving one local search around the minimum point is:

(the number of grid points) x (4) x (the number of soils) + 4

3.6 Translational Slope Stability Analysis (WEDGE)

One potential mode of failure of earth slopes involves planar sliding of a coherent mass of soil along natural or artificial boundaries between different soils. The sliding mechanism involves three distinct elements: one or more "active" (driving) wedges, a neutral or driving "central block," and one or more "passive" (resisting) wedges of soil. These elements are illustrated in Figure 20a. The factor of safety against this form of stability failure is a function of the size, position, and relative strength characteristics of the materials along the sliding surface for each wedge or block. This method is described in the Department of the Navy's NAVFAC Design Manual 7.1, Chapter 7, section 3.4 (1982). The translational analysis routine of GARDS employs this method to determine the minimum factor of safety for numerous central block, active/passive wedge combinations.

The translational wedge analysis applies primarily to stratified sections, especially where stratum boundaries are inclined or where a stratum with low shear strength exists. Even so, a rotational stability analysis may yield a lower factor of safety for the Section and should always be checked.

3.6.1 Wedge and Block Boundaries

The lateral boundaries of the central block are vertical and chosen automatically as a function of the Section geometry or as specified by the user. The program systematically varies the locations of the central block sides and remembers the lowest factor of safety and corresponding failure surface for each trial.

The active wedge is automatically defined on the up-slope (heel) side of the central block. The failure surface for the active wedge begins at the base of the central block and rises through the soil at an angle to the horizontal of $45 + \phi/2$ degrees until it intersects an overlying soil layer. The failure surface through this and each successive soil is determined using the $45 + \phi/2$ criteria until the failure surface intersects the ground surface of the Section.

The passive wedge is automatically defined on the down-slope (toe) side of the central block. The failure surface rises through the soil at an angle to the horizontal of $45 - \phi/2$ degrees intersecting each overlying soil layer and the ground surface as for the active wedge.

3.6.2 Program Operation

The program is intended to determine the lowest factor of safety or most probable failure surface through the Section. This is done by systematically varying the vertical side boundaries of the central block (starting points of the active and passive failure surfaces). This may be accomplished automatically or as specified by the user.

For the automatic search sequence, three x-coordinates (horizontal) must be established: a) the high point of the surface line of the Section ("highpoint"); b) the left point of the leftmost soil boundary line segment which slopes at least 15 percent up toward the highpoint ("left limit"); and c) the right point of the rightmost soil boundary line segment which slopes at least 15 percent up toward the highpoint ("right limit").

The first central block is set so the left side is at the "left limit." The right side is then set one "increment" toward the "highpoint." The base of the first central block is the first soil boundary line below the surface line of sufficient length to extend to both central block sides.

After the initial central block has been tested, the vertical side boundaries of the central block are changed in the following sequence:

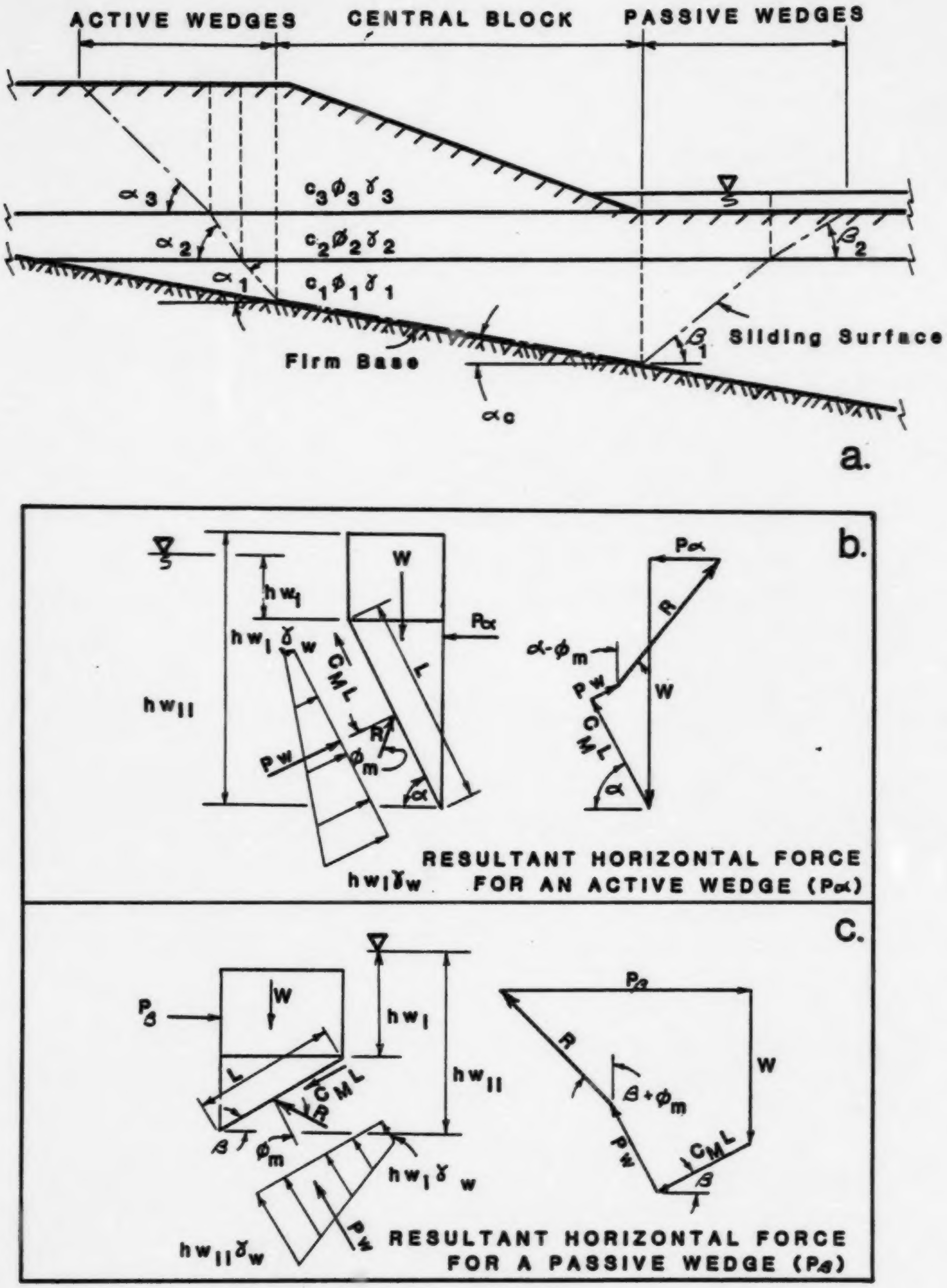

ACTIVE WEDGES
CENTRAL BLOCK
PASSIVE WEDGES
α3
c3 φ3 γ3
α2
c2 φ2 γ2
α1
c1 φ1 γ1
β2
β1
Sliding Surface
Firm Base
αc
a.
b.
hw I
hw I γw
hw II
W
Pα
L
CML
R
Pw
φm
α
α-φm
RESULTANT HORIZONTAL FORCE
FOR AN ACTIVE WEDGE (Pα)
hw I γw
c.
Pβ
W
L
CML
R
β
φm
hw I
hw II
hw I γ w
hw II γw
Pw
R
β+φm
Pw
CML
β
RESULTANT HORIZONTAL FORCE
FOR A PASSIVE WEDGE (Pβ)

Figure 20. Elements of the Translational (Wedge) Slope Stability Analysis

1) From the top down for all soil boundary layers which extend to both central block sides (central block expanded vertically over all soil layers before expanding horizontally)

2) The x-coordinate of the active side (heel) of the central block is moved one increment toward the "highpoint" and step 1 is repeated.

3) When the heel passes the "highpoint," the passive side (toe) of the central block is moved one increment toward the "highpoint," the heel is started at one increment away from the toe, and steps 1 and 2 are repeated.

4) When the toe passes the "highpoint," the above three steps are repeated on the other side of the Section with the toe beginning at the "right limit" and the heel one increment toward the "highpoint."

In all cases, the user may specify the increment for widening the central block or may use the default increment of eight feet.

For the manual search sequence, the user simply specifies the x-coordinates of the active (heel) and passive (toe) sides of the central block, and the program tests the specified central block for each soil layer in the Section. Either the default or user-defined increment may be used.

The foregoing has described the routine used to vary the position and dimensions of the central block. The following is a more general overview of the program sequence:

A. Determine central block and active/passive wedge boundaries.

B. Calculate weight, hydraulic force, length and angle of failure for all elements.

C. Set trial factor of safety.

D. Compute resultant force for all elements.

E. Sum resultant force for all elements.

F. Vary trial factor of safety until all resultant forces are in equilibrium (sum = 0).

G. Repeat A-F for all layers.

H. Perform above steps for all central blocks as described in paragraph 3.6.2.

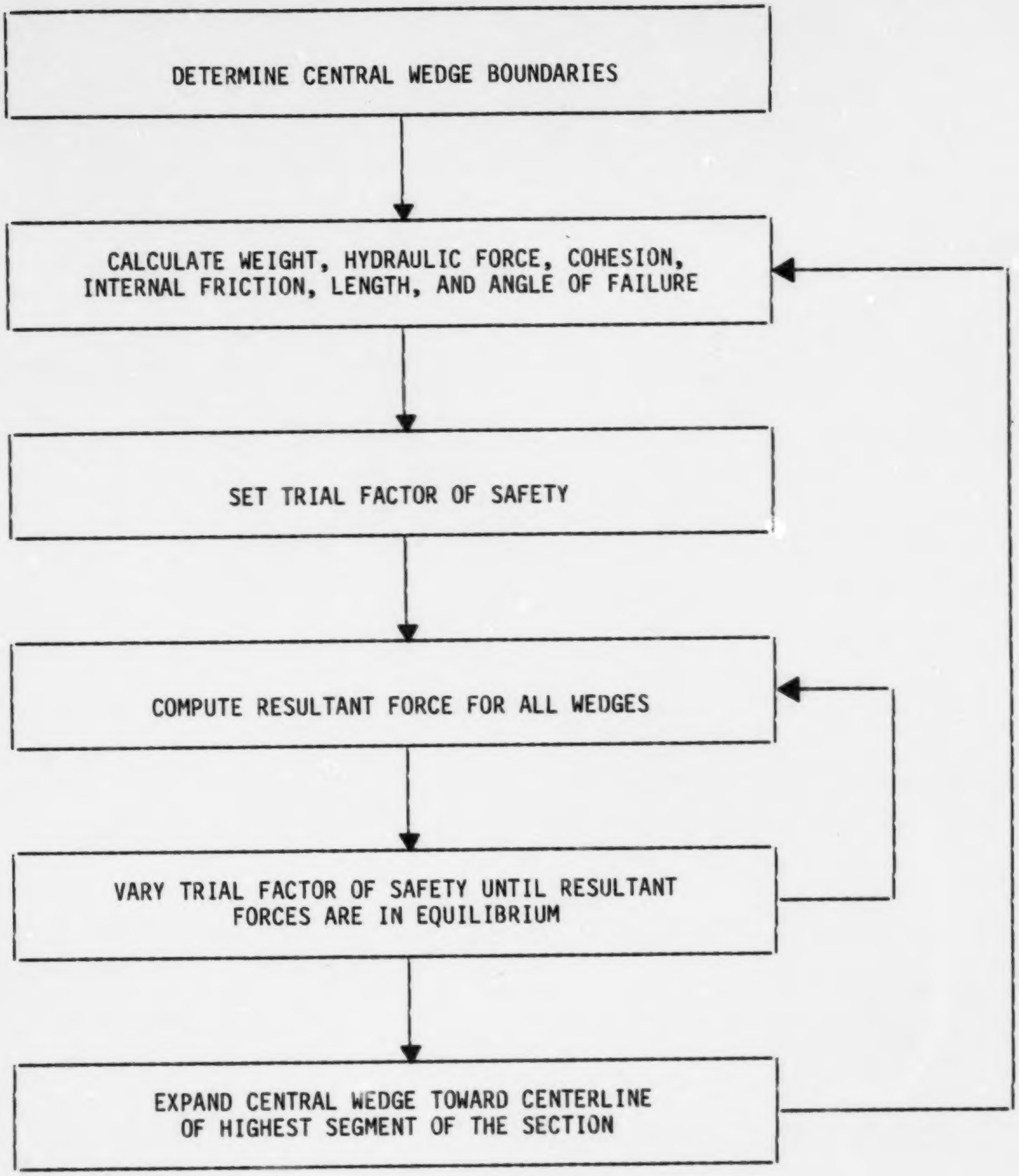

DETERMINE CENTRAL WEDGE BOUNDARIES
CALCULATE WEIGHT, HYDRAULIC FORCE, COHESION, INTERNAL FRICTION, LENGTH, AND ANGLE OF FAILURE
SET TRIAL FACTOR OF SAFETY
COMPUTE RESULTANT FORCE FOR ALL WEDGES
VARY TRIAL FACTOR OF SAFETY UNTIL RESULTANT FORCES ARE IN EQUILIBRIUM
EXPAND CENTRAL WEDGE TOWARD CENTERLINE OF HIGHEST SEGMENT OF THE SECTION

Figure 21: Flow chart of Translational Analysis

3.6.3. Strength Parameters

The mobilized strength of each soil is used in this analysis. The mobilized shear strength of a soil equals the design strength divided by the selected factor of safety against sliding failure. Figures 20b and 20c illustrate the force relationships for each element in the form of a "force polygon." Construction of a force polygon is not required, however, since the force equations include the necessary trigonometry to perform the vector analysis automatically; Figures 20b and 20c are presented for the purpose of background information only.

3.6.4 Output

Program output includes the lowest factor of safety calculated for the Section and includes the X-Y coordinates of the endpoints of the line segments comprising the critical failure surface and the hydraulic condition for which the analysis was made.

3.6.5 Program Limitations

This method of analysis assumes plane failure surfaces and homogeneous and isotropic soil properties.

The program only considers central block failure along part or all of one soil boundary line at a time, although the failure may extend across several segments of the soil boundary line.

3.7 Recommended Minimum Safety Criteria

3.7.1 Slope Stability Analysis

Recommended minimum factors of safety for slope stability analysis generally are set by the geotechnical engineer in charge of design. The basis for the determination customarily is a combination of convention and site-specific engineering judgment. Table 2 presents recommended minimum values for both rotational and translational slope stability analysis for the various soil strength conditions which may apply. Note that the reported minimum values are slightly higher than those for comparable situations in either of the two references cited. This reflects the general premise that factors such as "danger to human life or the environment" are paramount in hazardous waste management. In other words, the minimum recommended values for factors of safety in Table 2 have not been reduced to reflect lower levels of acceptable risk where the cost of repair or the danger to human life is considered to be small.

3.7.2 Settlement Analysis

The settlement block of GARDS computes the settlement of each soil layer beneath the dike at each toe and crest point and at the centerline of the dike. Differential settlements are computed toe-to-crest, crest-to-centerline, and toe-to-centerline on the upstream and downstream sides of the dike. Results are reported in the summary output by layer beneath the dike instead of by soil numbers. If a soil layer is not present beneath the dike, or has a settlement value of zero, the result for this layer is not reported in the summary output. The total and differential settlement values and the layers for which they are reported are illustrated in Figure 22.

Although it is difficult to establish acceptable limits of differential settlement for all conceivable dike designs, results in excess of the proposed maximum permissible values shown in Figure 22 are indicative of conditions or a proposed design which should be further investigated by a qualified geotechnics professional.

3.7.3 Liquefaction

The dike and foundation may be analyzed for liquefaction potential based upon procedures developed by Seed and Idress (1983). The procedure applies mainly to site conditions involving sand or silty sand strata occuring below a level ground surface, but may also be applied to less susceptible clayey soil if desired. The analysis is performed automatically, based upon soil parameters identified in Table 3.

Factors which most influence liquefaction potential are: soil type, relative density, initial confining pressure, and the intensity and duration of earthquake motion.

The intensity of earthquake motion is measured by the maximum surface acceleration, a_{max} (also used in slope stability analysis with CD strength parameters). For any confining pressure condition, susceptibility to liquefaction increases with increasing maximum surface acceleration.

The duration of earthquake motion defines the probable number of stress cycles to which a soil layer may be subjected. For any given soil and site-specific maximum ground surface acceleration (a_{max}) combination, there exists a specific threshold number of stress repetitions at the level of a_{max} beyond which liquefaction will occur. The measure of the maximum duration of earthquake motion, which defines the site-specific critical number of stress cycles, is termed the earthquake magnitude, M.

The maximum ground surface acceleration, a_{max}, and the design earthquake magnitude, M, should be determined by the project consulting engineer. Figure 1 in Appendix A gives a_{max} values for various seismic risk zones. Table 1, Appendix A, contains probabilistic design magnitudes for various seismic source zones shown in Figure 2, Appendix A. The ground surface acceleration and earthquake magnitude data should be considered as minimums unless special site conditions exist which warrant the use of a lower values (included in this manual for reference purposes only).

Strictly speaking, liquefaction results are either positive or negative, positive meaning that liquefaction will occur under the Section and seismic conditions assumed. In other words, a factor of safety of 1.0 or less should be interpreted as meaning that the Section is susceptible to liquefaction. Given the uncertainties involved in establishing Section and seismic parameters, it is recommended that a minimum acceptable factor of safety of 1.3 be used for all analyses. Liquefaction results are reported in the summary output as a tabulation of all soil layers, and points within these layers that have a factor of safety less than or equal to 2.50.

TABLE 2. RECOMMENDED MINIMUM FACTOR OF SAFETY FOR ROTATIONAL AND TRANSLATIONAL SLOPE STABILITY ANALYSIS

SHEAR STRENGTH PARAMETER	CONFIDENCE OF STRENGTH MEASUREMENT	RECOMMENDED MINIMUM FACTOR OF SAFETY
UU (end of construction, no waste or pool containment)	low(1) high(2)	1.40 1.20
CU	low high	1.50 1.30
CU (drawdown pool condition)	low high	1.40 1.20
CD (long-term, no seismic effects)	low high	1.60 1.40
CD (long-term with seismic effects)	low high	1.50 1.30

(1) The confidence of the strength measurements is lowest when the soil conditions are complex and when the available strength data do not provide a consistent, complete, or logical picture of the strength characteristics.

(2) The confidence of the strength measurements is highest when the soil conditions are uniform and high quality strength test data provide a consistent, complete and logical picture of the strength characteristics.

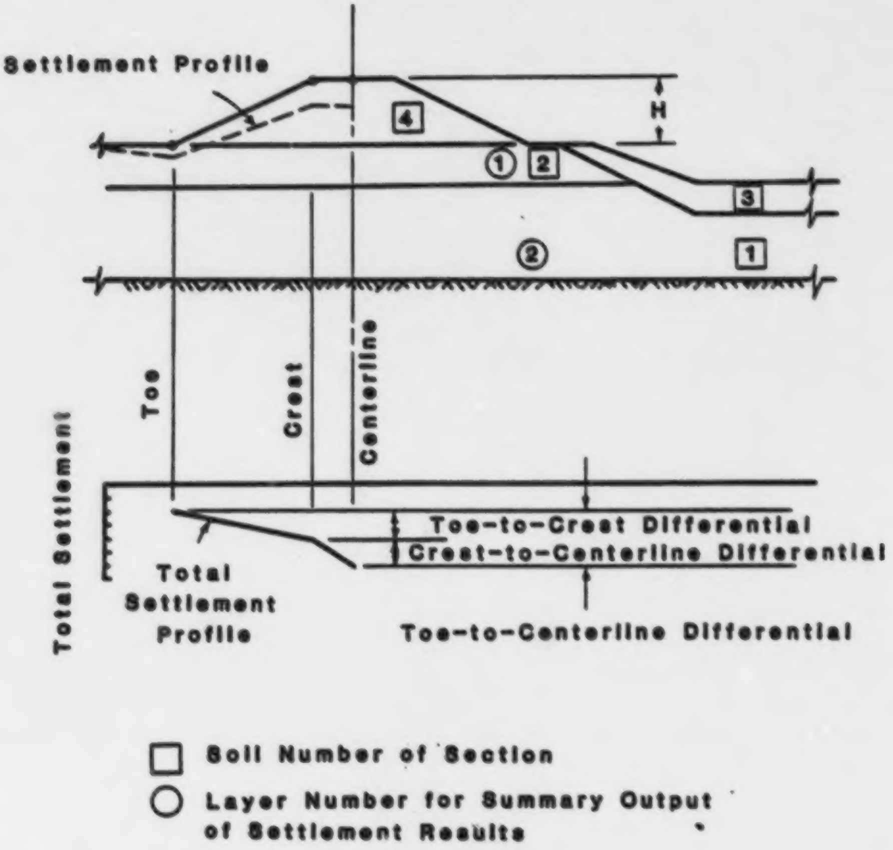
(3) Seismic effects applicable to CD soil strength conditions only

(4) If the dike exceeds 30 feet in height, add 0.10 to the recommended minimum factor of safety for each case.

(5) Adapted from:

a. "EPA Dike Stability Workshop Manual," Waterways Experiment Station, Tables 1 and 12, October 12, 1983.

b. D'Appolonia Consulting Engineers, 1975, and Federal Register, 1977; After: Huang, Y.H., "Stability Analysis of Earth Slopes, Table 2.3, Van Nostrand Reinhold Company, Inc., 1983.


Settlement Profile
H
4
① 2
3
②
1
Toe
Crest
Centerline
Total Settlement
Toe-to-Crest Differential
Crest-to-Centerline Differential
Total Settlement Profile
Toe-to-Centerline Differential
☐ Soil Number of Section
○ Layer Number for Summary Output of Settlement Results

NOTE: No scale; settlements exaggerated for illustrative purposes

RECOMMENDED DIFFERENTIAL SETTLEMENT LIMITS

TYPE	PROPOSED SAFE DIFFERENTIAL LIMIT
toe-to-crest	0.010 H
crest-to-centerline	0.002 H
toe-to-centerline	0.012 H

where H = the maximum thickness of the dike

Figure 22. Dike settlement illustration and recommended differential settlement limits

4.0 GARDS APPLICATION

4.1 Special Control Features

- Throughout the GARDS package, the user is prompted to input data or respond to questions regarding the sequence of program operation. In all cases where the proper response is either 'yes' or 'no,' the program recognizes a default as 'yes.' In other words, if the correct response is 'yes,' the user may simply press the return key <CR> and the program will recognize this as a 'yes' response. If the proper response is 'no,' the user must type either 'n' or 'N' followed by <CR>. The responses 'no' or 'No' are not recognized as equivalent to 'n' or 'N' and are therefore interpreted as 'yes.'

  In all cases, the default option appears enclosed in brackets in the interactive prompt on the monitor screen (...?[Y]/N, for example).

- In cases where the proper response to an interactive prompt is an integer or decimal number, the return key <CR> may be used to input '0' or '0.0,' respectively.

- When the computer is in an interactive prompt mode (waiting for a response from the user) the user may break out of the active program block by pressing the CTRL and BREAK keys simultaneously. The user may then return to the main command menu by typing MENU <CR>. This feature is useful if the user wishes to review only a portion of the results contained in the output summary block, for example.

- If the user encounters a 'fatal' error resulting in the return to the disk operating system, as indicated by the appearance of the DOS prompt (A> or C>), the user may return to the main command menu without erasing the active data file by typing MENU <CR>. If the user types GARDS <CR>, the aborted data file will be erased and the user must start over again.

- When the computer is in an interactive prompt mode (waiting for a response from the user) the user may obtain a hard copy of the monitor screen contents by pressing the shift (↑) and PRT SC keys simultaneously. This feature will, of course, only function if the printer is on and will not function when the computer is in a computational mode as indicated by the word 'working' on the monitor screen.

4.2 System Configuration and Getting Started

The GARDS package is a multi-diskette software package. It may be installed only on IBM-PC/XT or compatible systems with a hard disk, the IBM color graphics adapter or compatible graphics card, and an IBM graphics compatible dot matrix printer.

In order to print the graphs, the GRAPHICS.COM file should be present in your AUTOEXEC.BAT file. If it is not present or you are not sure, type GRAPHICS <CR> before starting GARDS.

The GARDS package may be installed in your system as follows:

1. Make sure there are 2.0 MB's free on the hard disk
2. Insert the "install GARDS" diskette into Drive A
3. Type A: <CR>
4. Type INSTALL <CR>
5. Insert the other diskette when the program prompts you to do so
6. The GARDS package will be installed in a directory named C:\GARDSDIR
7. To use the program, you must be in the directory GARDSDIR. To get to this directory, type CD \GARDSDIR <CR>
8. To start execution of the GARDS package, type GARDS <CR> and follow the user-friendly instructions

4.3 Building a Data File

The data file contains the input parameters which define the geometric, hydraulic, and physical soil parameters for the dike conditions under study.

As illustrated in Figure 12 (p. 25), a data file may be input in a step-by-step manner using one of two input options:

1. Initial data entry with text explanation and graphical examples
2. Initial data entry without text explanations

or, may be input automatically using the third input option:

3. Data entry using an existing input data file

With options 1 and 2, the program calls for project and data file identification, followed by site seismic parameters, Section geometry, soil parameters, and the selection of hydraulic boundary conditions and other analytical options.

Input rules and the explanations of required input data are thoroughly covered in the interactive text accompanying input option 1. Selected rules and explanations are reproduced in the following pages as a reference source so that the user need not tie up the computer to prepare the input data.

4.3.1 Project I Identification

Any alpha-numeric name, up to fifty-five characters in length, which identifies the project.

4.3.2 Data File Name

Any alpha-numeric name, up to eight characters in length, which uniquely identifies the input data file. For future reference, the file name should identify the project, the fact that it is a BASE file, and the hydraulic boundary condition modeled. For example, the file name 'CHB2' might be used to denote the 'Center Hill' project, 'Base' data file, hydraulic condition '2.'

4.3.3 Site Seismic Parameters

- The seismic coefficient is used to compute the forces imposed on the Section by earthquake activity. The coefficient is a factor between 0.0 and 0.27, depending upon the seismic risk associated with the site. Seismic coefficients for various seismic risk areas are presented in Figure A-1 in Appendix A.
- The design earthquake magnitude (M) is used in liquefaction analysis. Approximate values of M are presented in Figure A-2 and Table A-1 in Appendix A for various seismic source zones. A site-specific value determined by a geotechnics professional is preferred in all cases and should be used if available.

4.3.4 Section Geometry

A fundamental consideration of all analyses described herein is proper characterization of the dike system under study. Characterization consists of defining the geometry of the various different soil layers of the system and specifying several laboratory-determined test parameters used to model the behavior of each soil under anticipated field conditions. Overall system geometry is defined by inputting scaled X-Y coordinate data for the lower boundary of each soil layer as illustrated in Figure 23a, b and c. These figures are also presented as part of the interactive explanation in input option 1. Note that input of basic geometry comprises the numbering of soil boundary lines, specifying the number of points on each boundary line, and entering the X-Y coordinates for each point on each boundary line. Input rules for Section geometry are as follows:

4.3.4.1 Soil Boundary Lines

1) A soil boundary line consists of one or more straight line segments

2) Boundary lines are numbered in ascending order, starting with the bedrock or competent stratum at the base of the Section

3) A bedrock or competent stratum boundary line must be defined for the Section in all cases and must be assumed if it does not exist

4) The bedrock or competent stratum boundary line must be a single straight line (any orientation except vertical) defined by its endpoints

5) The lowermost boundary line defines both the top of bedrock or competent stratum at the bottom of the Section, and the base of the first overlying soil stratum

6) Subsequent boundary lines define only the base of successively higher soil strata

7) A boundary line with a lower number must not lie above a line with a higher number

   - Different numbering sequences along different imaginary vertical lines through the Section are sometimes necessary where sloping or discontinuous strata are involved. In such cases, numbers should be in ascending but not necessarily consecutive order as shown on lines A, B, and C in Figure 24.

8) The last, or uppermost, boundary line is also called the "surface line"

9) The surface line defines the ground surface

10) The surface line includes the water surface if a pool of water exists next to a dike

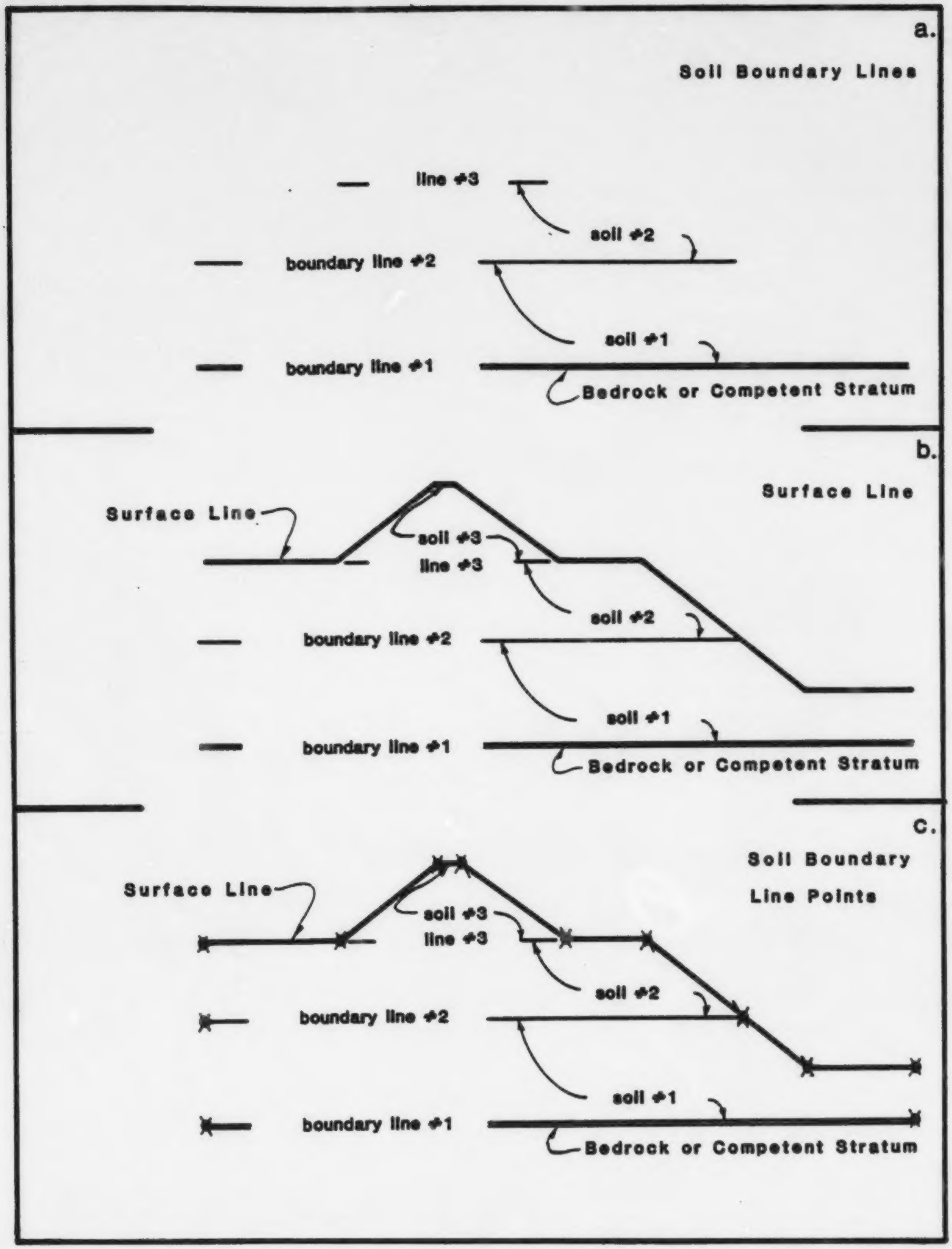

a.
Soil Boundary Lines
line #3
soil #2
boundary line #2
soil #1
boundary line #1
Bedrock or Competent Stratum
b.
Surface Line
Surface Line
soil #3
line #3
soil #2
boundary line #2
soil #1
boundary line #1
Bedrock or Competent Stratum
c.
Soil Boundary
Line Points
Surface Line
soil #3
line #3
soil #2
boundary line #2
soil #1
boundary line #1
Bedrock or Competent Stratum

Figure 23: Section geometry input (see Input Option 1)

11) If the surface line intersects the bedrock or competent basal stratum, it must terminate at that point

12) The bedrock boundary line cannot be used as a surface line

13) The surface line must be counted in the "total number of soil boundary lines"

14) Each soil is identified by a number corresponding to the number of the soil boundary line serving as its base

15) The total number of soils is one less than the number of boundary lines (no soil above uppermost boundary line or "surface line")

16) An above-ground pool of water should be considered as a separate soil with a unit weight of 62.4 PCF and zero cohesion and internal friction

17) A maximum of sixteen soil boundary lines, including the surface line, is permitted (sixteen soil boundary lines permits a maximum of fifteen soils)

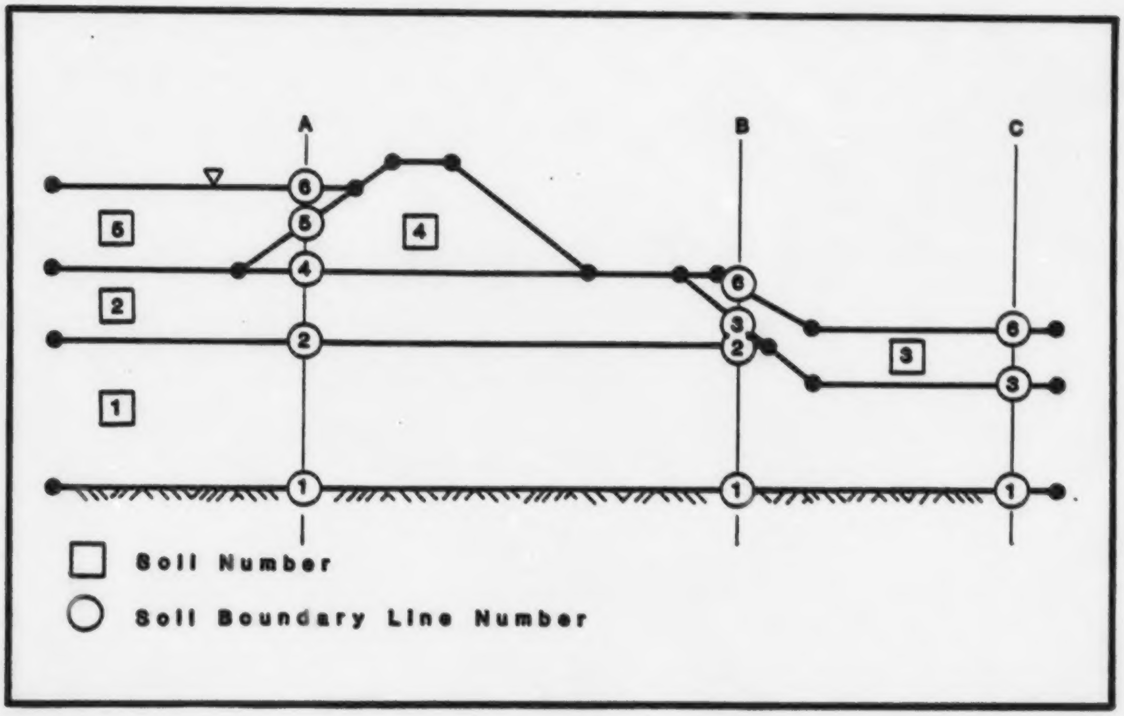


Figure 24. Soil boundary line numbering sequence example

4.3.4.2 Boundary Line Points

1) Each boundary line is defined by up to a maximum of 40 points

2) These points are numbered consecutively from left to right

3) Left to right is the positive X direction

4) When two boundary lines intersect, the intersecting point has two numbers--one number for each boundary line

5) The endpoints of the lowest and uppermost boundary lines and piezometric surface (if any) should be extended as far to the left and to the right as practical

6) The beginning and endpoints of soil boundary line 1 (base of soil 1 and top of bedrock or competent stratum) and the surface line must have the same X-coordinates

4.3.4.3 Boundary Line Point Coordinates

1) Boundary line joints are identified by X-Y coordinates

2) Place the origin as far to the left and as far down as practical (however, any origin may be used)

3) Use the same scale along both coordinate axes

4) Negative coordinates may be used if needed

Examples of Section geometry input are provided in the interactive explanations accompanying input option 1 (simplified example) and also as part of the GARDS Example Section presented in section 5.0 of this manual (more complex example). In all cases, the user should sketch the Section; number and identify the boundary lines, points and X-Y coordinate data; and summarize this input data on permanent input data sheets prior to data entry. Blank input data sheets are provided in Appendix C.

4.3.5 Soil Parameters

Soil parameters necessary for the analysis of slope stability, settlement, and liquefaction potential are defined in the interactive explanations accompanying input option 1.

Input of these parameters for each soil is a straightforward, interactive procedure in GARDS. In the typical case, the user enters the appropriate values of several parameters from a prepared Soil Property Data Sheet for each soil in the Section. It is assumed that the various input values have been supplied to the reviewer by the geotechnics professional responsible for design.

Input of all soil parameters for all soils is desirable and will permit the user to perform any analysis option he choses. In some cases (perhaps the rule rather than the exception), the user may find that the available data is incomplete. In such cases, the user may proceed to perform all analyses for which sufficient data does exist. Table 3 presents the necessary minimum soil parameters and unit of measurement for each stability analysis option. If, for example, the user wishes only to perform a straightforward rotational slope stability analysis, input data required for settlement analysis (compression index, etc.) is not essential and may be assigned a value of zero. Likewise, if the rotational stability analysis is to be performed only for the UU (unconsolidated-undrained) soil strength case, then, strictly speaking, CU and CD parameters are not required.

4.3.5.1 Internal Data Limits Check

Soil parameters often vary between broad limits. The intent of the internal data limits check in GARDS is not to validate input parameters, but to guard against inadvertent typographical error. Table 4 presents the typical limits assigned to the various soil parameters used in GARDS. Each input datum is automatically compared against the typical range assigned to that parameter. If the value falls outside the range, the user is so notified and immediately given the opportunity to change the value while in the input block (no need to call the Input Data Check and Edit Block from the command menu). The user may override this error trap routine, but should not do so without technical justification.

4.4 Echo Check and Edit

At the end of input operations, or at any other time the main Command Menu is displayed, the user may choose menu option 4 to check or edit the contents of the active data file. A graphics check is part of this general check/edit function, and is generally used to perform a visual check of Section geometric continuity before proceeding.

The graphics check involves a "plot" subroutine which allows the user to use a "window" to view any part of the Section at any scale. The following window commands used to adjust the viewing area are presented below for reference.

U moves the window UP
D moves the window DOWN
L moves the window LEFT
R moves the window RIGHT
C makes the profile appear CLOSER
F makes the profile appear FARTHER away
S is used to SET the SCALE
X is used to set the lower left X coordinate
Y is used to set the lower left Y coordinate
H will return the user to the HELP screen
T allows you to add text to the Section plot before printing
Q is used to QUIT and return to the main Command Menu

For a printout of the Section or other intermediate information, the user should press SHIFT and PRTSC keys at the same time.

TABLE 3. MINIMUM DATA REQUIREMENTS FOR STABILITY ANALYSIS OPTIONS

SOIL PARAMETER	UNITS	STABILITY ANALYSIS OPTIONS			
		ROTATIONAL	TRANSL.	SETTLEMT.	LIQUEF.
1. Cohesion* (UU,CU,CD cases)	pounds/sq.ft. (psf)	x	x		x CD
2. Angle of internal friction* (UU,CU,CD cases)	degrees	x	x		
3. Total (wet) unit weight	pounds/cu.ft. (pcf)	x	x	x	x
4. Clay content	percent (0 to 100)				x
5. Overconsolidation ratio	unitless (decimal)			x	
6. Initial void ratio	unitless (decimal)			x	
7. Compression index	unitless (decimal)			x	
8. Recompression index	unitless (decimal)			x	
9. Hydraulic conductivity** (permeability, k)	ft/yr				
10. Median grain size	mm				x
11. Plasticity index (PI)	percent (0 to 100)				x
12. Liquid limit (LL)	percent (0 to 100)				x
13. Standard penetration number (N)	unitless (integer)				x

*Required strength case dependent upon hydraulic boundary condition selected
**Used only in hydraulic analysis

TABLE 4. TYPICAL RANGE OF SEISMIC, SECTION, AND SOIL PARAMETERS

SEISMIC PARAMETER	RANGE (Inclusive)
Seismic coefficient, a_{max}	(0 to 0.27)
Design earthquate magnitude, M	(5.25 to 8.5)
SECTION PARAMETER	
Number of soil boundary lines	(0 to 16)
Number of points on a boundary line	(0 to 40)
SOIL PARAMETER	
Cohesion (psf), c	
Unconsolidated undrained (UU)	(0 to 3500)
Consolidated undrained (CU)	(0 to 2500)
Consolidated drained (CD)	(0 to 2500)
Internal angle of friction (degrees), ϕ	
Unconsolidated undrained (UU)	(0 to 30)
Consolidated undrained (CU)	0 or (10 to 35)
Consolidated drained (CD)	0 or (10 to 45)
Total (wet) unit weight (pcf), γ_t	(62 to 145)
Clay content (%)	(0 to 100)
Overconsolidation ratio	0 or (0.5 to 5.0)
Initial void ratio, e_0	0 or (0.3 to 1.3)
Compression index, c_c	0 or (0.01 to 1.0)
Recompression index, c_r	0 or (0.005 to 0.2)
Permeability (ft/yr), k	0 or (0.01 to 50,000,000)
Median grain size (mm), D_{50}	0 or (0.0002 to 100)
Plasticity index (%), PI	(0 to 50)
Liquid limit (%), LL	(0 to 80)
Standard penetration number, N	(0 to 100)

5.0 EXAMPLE SECTION

This section describes the general input and analytical procedures for two distinct Sections which represent different stages of construction at a proposed hazardous waste disposal site. The site is a level floodplain with a shallow groundwater table (higher than the planned depth of the cell). The objective is first to see if a dike and landfill can safely be constructed under these site conditions and, secondly, to determine the safety of the system under an assumed flood or static pool condition in the long term. Although in practice, the user might analyze additional intermediate Sections, this example assumes concurrent cell excavation and dike construction and is limited to:

- Data entry of the BASE data file
- Slope stability and settlement analysis under the Shallow Seepage hydraulic boundary condition
- Slope stability and liquefaction analysis under the Confined Pool Seepage hydraulic boundary condition

Generally speaking, there are two approaches to analyzing progressively more complex Sections in a staged-construction situation. The user may create an entirely new data file for each case using input options 1 or 2, OR the user may employ the file modification technique wherein the more complex case(s) is developed by editing the previous data file (Command Menu Option 4)

In most cases, the file modification technique is more expedient, but also requires more care on the part of the user. For the two examples herein, the file modification technique is used.

5.1 Input of the BASE Data File

Figure 25 shows the soil boundary lines and boundary line points defining the Section for the "BASE" data file. For this example, the soil number sequence at the dike centerline from the base of the Section up is 1, 2, 4. The soil number sequence at the base of the excavation for the cell is 1, 3 (soil 3 representing the clay liner). Input data sheets 1 through 14 include the basic Section geometry and soil parameters for the "BASE" data file.

GARDS is structured such that any time a data file is created (input options 1 or 2), the user is prompted to specify a hydraulic condition which

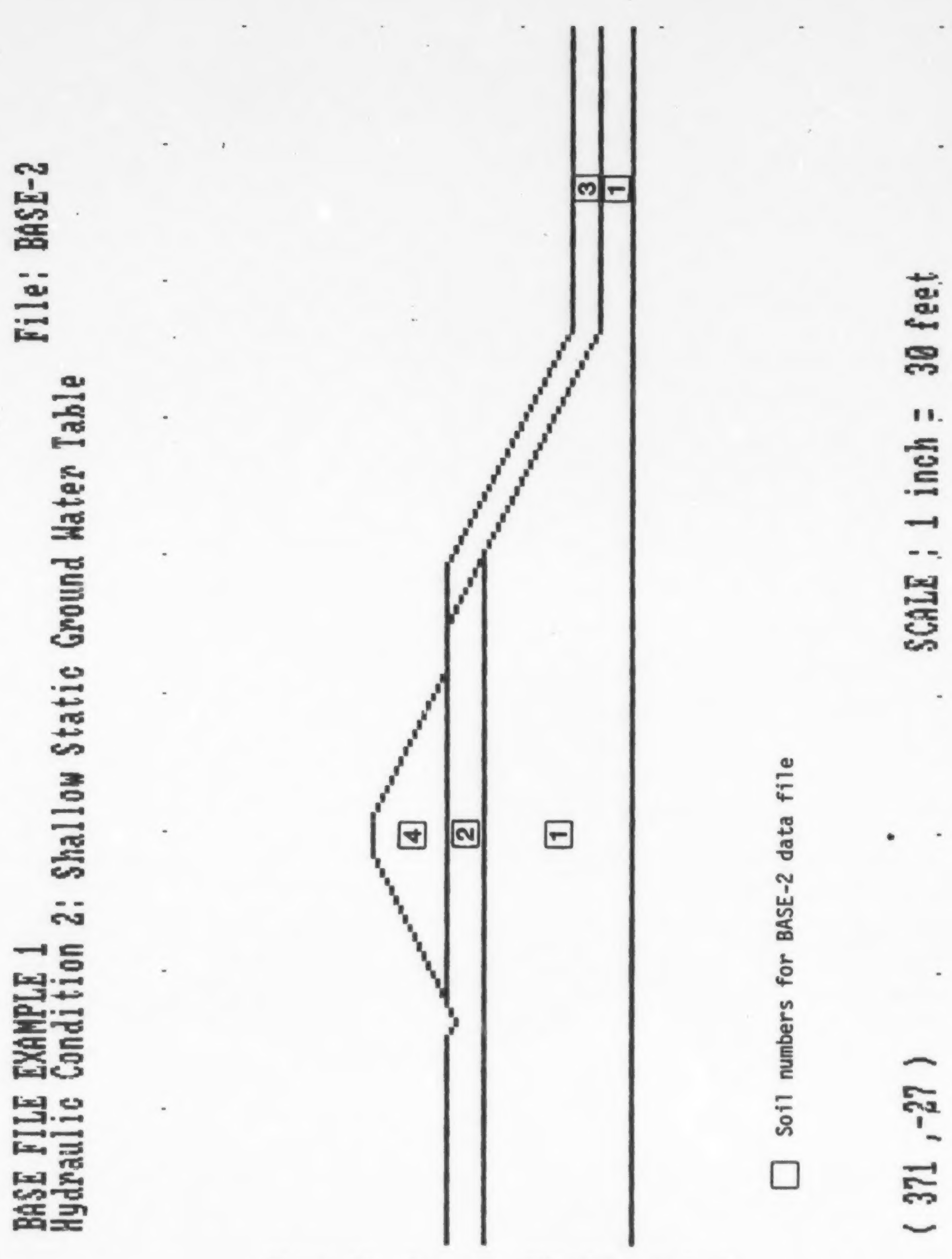

BASE FILE EXAMPLE 1
Hydraulic Condition 2: Shallow Static Ground Water Table
File: BASE-2
4
2
1
3
1
☐ Soil numbers for BASE-2 data file
(371 ,-27)
SCALE : 1 inch = 30 feet

Figure 25. Base data file for Example 1

is then executed before control is returned to the user. The user is also prompted to specify a search scheme for rotational slope stability before control is returned. To take advantage of this, the user should input a "BASE" data file which contains the hydraulic and search scheme criteria for the Section to be tested.

In this example, the "BASE" data file created has been named "BASE-2" to reflect hydraulic boundary condition No. 2 (Shallow Seepage). The project identification has been input as "BASE FILE, EXAMPLE 1." Note that the clay liner (soil no. 3) is part of the Section even though the analysis is for condition immediately after construction of the dike and cell and before the placement of the liner. For hydraulic analysis under the Shallow Seepage condition, the liner routinely is ignored by entering its soil number as part of the drainage specification input associated with input option 1 or 2.

After data input and automatic hydraulic analysis, the user SAVES the BASE-2 file with its hydraulic results using the Save File or Quit option (Command Menu Option 10).

Sheet 1 of 14

GARDS

Input Data Format

GENERAL INFORMATION

Project Identification: BASE FILE, EXAMPLE 1

Data File Name: BASE-2

Seismic Coefficient: 0.1

Design Earthquake Magnitude: 6.0

A complete data set for a given case consists of defining the basic geometry, soil properties, seepage conditions to be analyzed and the stability analysis option to be performed.

Forms for each of these criteria are provided. Use as many soil boundary line sheets as necessary to define the geometry, one soil boundary line per sheet. Also, use as many soil property sheets as necessary, one soil per sheet.

Sheet 2 of 14

A. DIKE GEOMETRY

Number of soil boundary lines for this section: 5

SOIL BOUNDARY LINE NO: 1

Number of points on soil boundary line #1 : 2

POINT NO.	X-COORD	Y-COORD	POINT NO.	X-COORD	Y-COORD
1	0	40	21		
2	818	40	22		
3			23		
4			24		
5			25		
6			26		
7			27		
8			28		
9			29		
10			30		
11			31		
12			32		
13			33		
14			34		
15			35		
16			36		
17			37		
18			38		
19			39		
20			40		

Sheet 3 of 14

SOIL BOUNDARY LINE NO: 2

Number of points on soil boundary line # 2 : 2

POINT NO.	X-COORD	Y-COORD	POINT NO.	X-COORD	Y-COORD
1	0	72	21		
2	521	72	22		
3			23		
4			24		
5			25		
6			26		
7			27		
8			28		
9			29		
10			30		
11			31		
12			32		
13			33		
14			34		
15			35		
16			36		
17			37		
18			38		
19			39		
20			40		

Sheet 4 of 14

SOIL BOUNDARY LINE NO: 3

Number of points on soil boundary line # 3 : 4

POINT NO.	X-COORD	Y-COORD	POINT NO.	X-COORD	Y-COORD
1	505	80	21		
2	521	72	22		
3	570	47	23		
4	818	47	24		
5			25		
6			26		
7			27		
8			28		
9			29		
10			30		
11			31		
12			32		
13			33		
14			34		
15			35		
16			36		
17			37		
18			38		
19			39		
20			40		

Sheet 5 of 14

SOIL BOUNDARY LINE NO: 4

Number of points on soil boundary line # 4 : 2

POINT NO.	X-COORD	Y-COORD	POINT NO.	X-COORD	Y-COORD
1	424	80	21		
2	496	80	22		
3			23		
4			24		
5			25		
6			26		
7			27		
8			28		
9			29		
10			30		
11			31		
12			32		
13			33		
14			34		
15			35		
16			36		
17			37		
18			38		
19			39		
20			40		

Sheet 6 of 14

SOIL BOUNDARY LINE NO: 5

Number of points on soil boundary line # 5 : 11

POINT NO.	X-COORD	Y-COORD	POINT NO.	X-COORD	Y-COORD
1	0	80	21		
2	416	80	22		
3	420	78	23		
4	424	80	24		
5	456	96	25		
6	464	96	26		
7	496	80	27		
8	505	80	28		
9	518	80	29		
10	570	53	30		
11	818	53	31		
12			32		
13			33		
14			34		
15			35		
16			36		
17			37		
18			38		
19			39		
20			40		

Sheet 7 of 14

B. SOIL PROPERTIES

Soil No: 1

Cohesion:

unconsolidated, undrained (PSF) 1000

or

1/2 unconfined compressive strength (PSF) --

consolidated, undrained (PSF) 400

consolidated, drained (PSF) 400

Angle of internal friction:

unconsolidated, undrained (degrees) 0

consolidated, undrained (degrees) 14

consolidated, drained (degrees) 28

Wet unit weight: (PCF) 115

Clay content: (%) 35

Overconsolidation ratio: 1.0

Initial void ratio: (decimal) 0.6

Compression index: (decimal) 0.05

Recompression index: (decimal) 0.008

Permeability: (ft/yr) 0.1

D_{50}:(mm) 0.002

Plasticity index:(%) 8

Liquid limit:(%) 25

Average standard penetration resistance: (blows/ft) 14

B. SOIL PROPERTIES

Soil No: 2

Cohesion:

unconsolidated, undrained (PSF) 200

or

1/2 unconfined compressive strength (PSF) -

consolidated, undrained (PSF) 150

consolidated, drained (PSF) 150

Angle of internal friction:

unconsolidated, undrained (degrees) 0

consolidated, undrained (degrees) 16

consolidated, drained (degrees) 30

Wet unit weight: (PCF) 110

Clay content: (%) 15

Overconsolidation ratio: 1.0

Initial void ratio: (decimal) 0.45

Compression index: (decimal) 0.08

Recompression index: (decimal) 0.01

Permeability: (ft/yr) 0.25

D_{50}:(mm) 0.01

Plasticity index:(%) 10

Liquid limit:(%) 20

Average standard penetration resistance: (blows/ft) 16

B. SOIL PROPERTIES

Soil No: 3

Cohesion:

unconsolidated, undrained (PSF) 1300

or

1/2 unconfined compressive strength (PSF) -

consolidated, undrained (PSF) 900

consolidated, drained (PSF) 1050

Angle of internal friction:

unconsolidated, undrained (degrees) 0

consolidated, undrained (degrees) 13

consolidated, drained (degrees) 27

Wet unit weight: (PCF) 130

Clay content: (%) 66

Overconsolidation ratio: 1.0

Initial void ratio: (decimal) 0.6

Compression index: (decimal) 0.25

Recompression index: (decimal) 0.10

Permeability: (ft/yr) 0.10

D_{50}:(mm) 0.001

Plasticity index:(%) 17

Liquid limit:(%) 38

Average standard penetration resistance: (blows/ft) 15

Sheet 10 of 13

B. SOIL PROPERTIES

Soil No: 4

Cohesion:

unconsolidated, undrained (PSF) 1200
or
1/2 unconfined compressive strength (PSF) -

consolidated, undrained (PSF) 600

consolidated, drained (PSF) 600

Angle of internal friction:

unconsolidated, undrained (degrees) 0

consolidated, undrained (degrees) 14

consolidated, drained (degrees) 29

Wet unit weight: (PCF) 128

Clay content: (%) 55

Overconsolidation ratio: 1.0

Initial void ratio: (decimal) 0.7

Compression index: (decimal) 0.12

Recompression index: (decimal) 0.02

Permeability: (ft/yr) 0.10

D_{50}:(mm) 0.001

Plasticity index:(%) 18

Liquid limit:(%) 40

Average standard penetration resistance: (blows/ft) 10

Sheet 11 of 14

C. DRAINAGE SPECIFICATION

Method of Input: x Internal Generation of Piezometric Surface

____ Manual Input of Piezometric Surface

INTERNAL GENERATION OF PHREATIC SURFACE

1. DEEP STATIC

Elevation of deep static groundwater table ____

2. SHALLOW SEEPAGE

Elevation of shallow seepage groundwater table 65

Soil number representing clay liner (0 if none) 3

3. FREE POOL SEEPAGE

Elevation of maximium upstream pool ____

Soil number representing clay liner (0 if none) ____

4. SHALLOW CONFINED SEEPAGE

Maximum shallow groundwater elevation ____

Design waste elevation in the cell ____

Soil number representing clay liner ____

5. CONFINED POOL SEEPAGE

Elevation of maximum upstream pool ____

Design waste elevation in the cell ____

Soil number representing clay liner ____

6. DRAWDOWN POOL

Elevation of maximum upstream pool ____

Soil number representing clay liner ____

Sheet 12 of 14

MANUAL INPUT OF PHREATIC SURFACE

POINT NO.	X-COORD	Y-COORD	POINT NO.	X-COORD	Y-COORD
1			21		
2			22		
3			23		
4			24		
5			25		
6			26		
7			27		
8			28		
9			29		
10			30		
11			31		
12			32		
13			33		
14			34		
15			35		
16			36		
17			37		
18			38		
19			39		
20			40		

Sheet 13 of 14

D. ROTATIONAL FAILURE SEARCH SCHEMES

☒ Internally generated grid search

☐ User defined grid search

Grid Point No.	X-Coordinate	Y-Coordinate
1		
2		
3		

Number of divisions between points #1 and #2:

Number of divisions between points #2 and #3:

X-increment for search:

Y-increment for search:

☐ User defined point search

Number of centers to be analyzed:

Point No.	X-Coordinate	Y-Coordinate
1		
2		
3		
4		
5		

X-increment for search:

Y-increment for search:

E. TRANSLATIONAL FAILURE (WEDGE) SEARCH SCHEMES

☒ Automatic wedge search

---------------- --

☐ User defined wedge

X-coordinate left side of central block ____________
X-coordinate right side of central block ____________

F. SOIL STRENGTH PARAMETERS

UU ☒ unconsolidated - undrained
CU ☐ consolidated - undrained
CD ☐ consolidated - drained

G. OTHER STABILITY ANALYSES

☒ settlement
☐ liquefaction

5.2 Execution of the Shallow Seepage Condition

During input of the BASE-2 data file, the hydraulic analysis was specified and performed, and the rotational slope stability search scheme was selected. The hydraulic analysis results and search scheme specification were then automatically added to the BASE-2 file.

To perform the stability analyses on the Section, the user is presented with the Main Command Menu and proceeds as follows (numbers in parentheses indicate Command Menu option):

1. Copy in the BASE-2 file (3)
2. Edit the BASE-2 file to model for slope stability analysis (4)
   - Rename Project Identification as desired to reflect the hydraulic condition associated with the slope stability analysis
   - Rename the data file so that it can be saved along with all results for this case ("BASE2EX1" used as new name in this example)
   - Assign the UU cohesion and total (wet) unit weight of soil No. 3 (clay liner) a value of zero (0) so that it will not contribute to the slope stability of the Section

(New input data sheets which reflect these file changes follow.)

3. Call Slope Stability Analysis option (6)
   - Specify UU strength parameters
   - Specify Rotational Slope Stability Analysis
4. Re-call Slope Stability Analysis option (6)
   - Specify Translational Slope Stability Analysis
   - Specify automatic wedge failure search scheme
   - Specify UU soil strength parameters
5. Call Settlement Analysis option (7)
6. Call Summary Output option (9)
7. Call Save File or Quit option (10); SAVE FILE! Return to main menu when prompted

The BASE2EX1 file renamed in step 2 and saved in step 7 now contains all results for all analyses performed under the Shallow Seepage case. The Summary Output for the Section under conditions specified in the BASE2EX1 file follows the new input data sheets used to modify the original "BASE-2" file.

Sheet 1 of ___

GARDS

Input Data Format

GENERAL INFORMATION

Project Identification: SHALLOW SEEPAGE CASE FOR EXAMPLE 1

Data File Name: BASE2EX1

Seismic Coefficient: - (no change)

Design Earthquake Magnitude: - (no change)

A complete data set for a given case consists of defining the basic geometry, soil properties, seepage conditions to be analyzed and the stability analysis option to be performed.

Forms for each of these criteria are provided. Use as many soil boundary line sheets as necessary to define the geometry, one soil boundary line per sheet. Also, use as many soil property sheets as necessary, one soil per sheet.

Sheet ___ of ___

B. SOIL PROPERTIES

Soil No: 3

Cohesion:

unconsolidated, undrained (PSF) 0

or

1/2 unconfined compressive strength (PSF) ___

consolidated, undrained (PSF) ___

consolidated, drained (PSF) ___

Angle of internal friction:

unconsolidated, undrained (degrees) ___

consolidated, undrained (degrees) ___

consolidated, drained (degrees) ___

Wet unit weight: (PCF) 0

Clay content: (%) ___

Overconsolidation ratio: ___

Initial void ratio: (decimal) ___

Compression index: (decimal) ___

Recompression index: (decimal) ___

Permeability: (ft/yr) ___

D_{50}:(mm) ___

Plasticity index:(%) ___

Liquid limit:(%) ___

Average standard penetration resistance: (blows/ft) ___

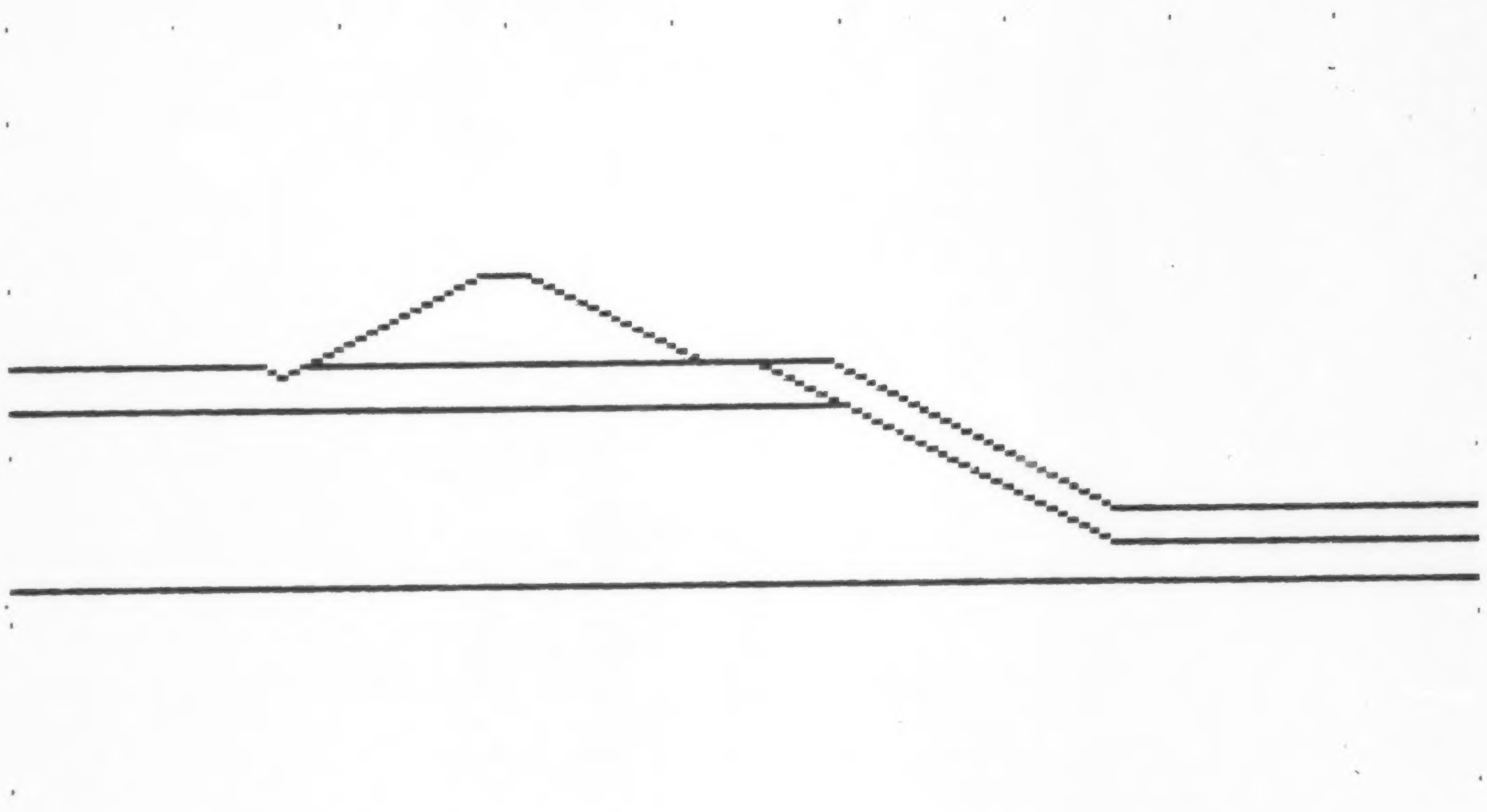
NOTE: Only modified parameters shown; all others are same as before (BASE-2 file) and do not require modification.

```
************************************************************************
*                                                                      *
*                        G A R D S   S U M M A R Y                     *
*                                                                      *
*    Project:  SHALLOW SEEPAGE CASE FOR EXAMPLE 1                      *
*       File:  BASE2EX1                                                *
*                                                                      *
*                          GARDS  Version 2.00                         *
*                             developed by                             *
*          Department of Civil and Environmental Engineering           *
*                       University of Cincinnati                       *
*                           under contract to                          *
*                 U.S. Environmental Protection Agency                 *
*                     Land Pollution Control Division                  *
*           Hazardous Waste Engineering Research Laboratory            *
*                                                                      *
************************************************************************
```

```
************************************************************************
*                         Site Characteristics                         *
************************************************************************
*                                                                      *
*      The seismic coefficient is. . . . . . . . . . . . . . . 0.10    *
*                                                                      *
*      The design earthquake magnitude is. . . . . . . . . . . 6.00    *
*                                                                      *
*      The maximum flood elevation in this case is . . . . .     0     *
*                                                                      *
*      The elevation of the seasonal high ground water is. .    60     *
*                                                                      *
*      The design waste elevation in the cell is . . . . . .     0     *
*                                                                      *
*      The soil number representing the clay liner is. . . .     3     *
*                                                                      *
************************************************************************
```

```
************************************************************************
*                          Section Geometry                            *
************************************************************************
*                                                                      *
*     The number of soil boundary lines for this section is  5         *
*----------------------------------------------------------------------*
*    Line  1        Point          X           Y                       *
*                   ------       ------      ------                    *
*                      1             0         40                      *
*                      2           818         40                      *
*----------------------------------------------------------------------*
*    Line  2        Point          X           Y                       *
*                   ------       ------      ------                    *
*                      1             0         72                      *
*                      2           521         72                      *
*----------------------------------------------------------------------*
*    Line  3        Point          X           Y                       *
*                   ------       ------      ------                    *
*                      1           505         80                      *
*                      2           521         72                      *
*                      3           570         47                      *
*                      4           818         47                      *
*----------------------------------------------------------------------*
*    Line  4        Point          X           Y                       *
*                   ------       ------      ------                    *
*                      1           424         80                      *
*                      2           496         80                      *
*----------------------------------------------------------------------*
*    Line  5        Point          X           Y                       *
*                   ------       ------      ------                    *
*                      1             0         80                      *
*                      2           416         80                      *
*                      3           420         78                      *
*                      4           424         80                      *
*                      5           456         96                      *
*                      6           464         96                      *
*                      7           496         80                      *
*                      8           505         80                      *
*                      9           518         80                      *
*                     10           570         53                      *
*                     11           818         53                      *
************************************************************************
```

SHALLOW SEEPAGE CASE FOR EXAMPLE 1 File: BASE2EX1
Hydraulic Condition 2: Shallow Static Ground Water Table



(371 ,-27) SCALE ; 1 inch = 30 feet

```
**********************************************************************
*                                                                    *
*                        Soil  1 Properties                          *
**********************************************************************
*                                                                    *
*                 Unconsolidated  Consolidated  Consolidated         *
*                   Undrained      Undrained      Drained            *
*                 ------------   ------------   ------------         *
*  Cohesion           1000           400            400     (lb/sq.ft) *
*  Phi Angle             0            14             28      (degrees) *
*--------------------------------------------------------------------*
*                                                                    *
*         Unit Weight . . . . . . . . . . .  115.000   (lb/cu.ft)    *
*         Clay Content  . . . . . . . . . .   35.000   (%)           *
*         Overconsolidation Ratio . . . .      1.000                 *
*         Initial Void Ratio  . . . . . . .    0.600                 *
*         Compression Index . . . . . . . .    0.050                 *
*         Recompression Index . . . . . . .    0.008                 *
*         Permeability  . . . . . . .          0.100   (ft/yr)       *
*         Median Grain Size . . . . . . . .    0.002   (mm)          *
*         Plasticity Index  . . . . . . . .    8.000   (%)           *
*         Liquid Limit  . . . . . . . . . .   25.000   (%)           *
*         Standard Penetration Number . .     14.000   (blows/ft)    *
**********************************************************************
```

```
**********************************************************************
*                                                                    *
*                        Soil  2 Properties                          *
**********************************************************************
*                                                                    *
*                 Unconsolidated  Consolidated  Consolidated         *
*                   Undrained      Undrained      Drained            *
*                 ------------   ------------   ------------         *
*  Cohesion            200           150            150     (lb/sq.ft) *
*  Phi Angle             0            16             30      (degrees) *
*--------------------------------------------------------------------*
*                                                                    *
*         Unit Weight . . . . . . . . . . .  110.000   (lb/cu.ft)    *
*         Clay Content  . . . . . . . . . .   15.000   (%)           *
*         Overconsolidation Ratio . . . .      1.000                 *
*         Initial Void Ratio  . . . . . . .    0.450                 *
*         Compression Index . . . . . . . .    0.080                 *
*         Recompression Index . . . . . . .    0.010                 *
*         Permeability  . . . . . . .          0.250   (ft/yr)       *
*         Median Grain Size . . . . . . . .    0.010   (mm)          *
*         Plasticity Index  . . . . . . . .   10.000   (%)           *
*         Liquid Limit  . . . . . . . . . .   20.000   (%)           *
*         Standard Penetration Number . .     16.000   (blows/ft)    *
**********************************************************************
```

```
************************************************************************
*                          Soil  3 Properties                          *
************************************************************************
*                                                                      *
*              Unconsolidated  Consolidated  Consolidated              *
*                 Undrained     Undrained      Drained                 *
*                                                                      *
*                ------------  ------------  ------------              *
*   Cohesion           0           900          1050     (lb/sq.ft)  *
*   Phi Angle          0            13            27      (degrees)  *
*----------------------------------------------------------------------*
*                                                                      *
*        Unit Weight . . . . . . . . . . .    0.000   (lb/cu.ft)       *
*        Clay Content  . . . . . . . . . .   66.000   (%)              *
*        Overconsolidation Ratio . . . .      1.000                    *
*        Initial Void Ratio  . . . . . .      0.600                    *
*        Compression Index . . . . . . .      0.250                    *
*        Recompression Index . . . . . .      0.100                    *
*        Permeability  . . . . . . .          0.100   (ft/yr)          *
*        Median Grain Size . . . . . . .      0.001   (mm)             *
*        Plasticity Index  . . . . . . .     17.000   (%)              *
*        Liquid Limit  . . . . . . . . .     38.000   (%)              *
*        Standard Penetration Number . .     15.000   (blows/ft)       *
************************************************************************
```

```
************************************************************************
*                          Soil  4 Properties                          *
************************************************************************
*                                                                      *
*              Unconsolidated  Consolidated  Consolidated              *
*                 Undrained     Undrained      Drained                 *
*                                                                      *
*                ------------  ------------  ------------              *
*   Cohesion          1200         600           600     (lb/sq.ft)  *
*   Phi Angle          0            14            29      (degrees)  *
*----------------------------------------------------------------------*
*                                                                      *
*        Unit Weight . . . . . . . . . . .  128.000   (lb/cu.ft)       *
*        Clay Content  . . . . . . . . . .   55.000   (%)              *
*        Overconsolidation Ratio . . . .      1.000                    *
*        Initial Void Ratio  . . . . . .      0.700                    *
*        Compression Index . . . . . . .      0.120                    *
*        Recompression Index . . . . . .      0.020                    *
*        Permeability  . . . . . . .          0.100   (ft/yr)          *
*        Median Grain Size . . . . . . .      0.001   (mm)             *
*        Plasticity Index  . . . . . . .     18.000   (%)              *
*        Liquid Limit  . . . . . . . . .     40.000   (%)              *
*        Standard Penetration Number . .     10.000   (blows/ft)       *
************************************************************************
```

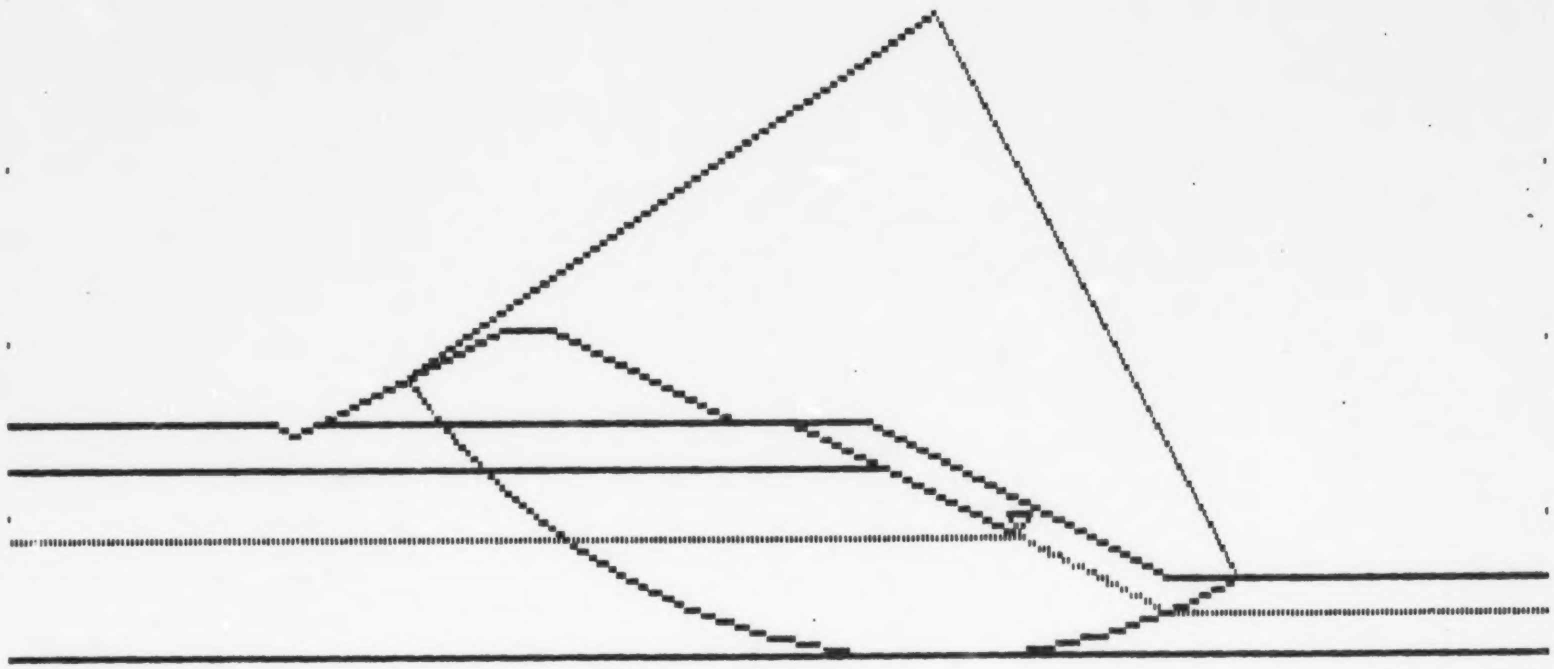
```
*************************************************************************
*                      Automatically Generated                          *
*             Piezometric Surface for Hydraulic Condition               *
*             2: Shallow Seepage                                        *
*************************************************************************
*                                                                       *
*                   Point           X             Y                     *
*                  ------        ------        ------                   *
*                       1             0            60                   *
*                       2           544            60                   *
*                       3           570            47                   *
*                       4           818            47                   *
*************************************************************************
```

```
**************************************************************************
*                           Hydraulics Results                           *
**************************************************************************
*                                                                        *
*        Seepage In  . . . . . . . .       0.000   (cu.ft/yr)            *
*                                                                        *
*        Seepage Out . . . . . . . .       0.000   (cu.ft/yr)            *
*                                                                        *
*        Critical Exit Gradient  . . .     0.000                         *
*                                                                        *
*        For this hydraulic condition there is no liner uplift.          *
*                                                                        *
**************************************************************************
```

```
**************************************************************************
*                                                                        *
*          R O T A T I O N A L   F A I L U R E   R E S U L T S           *
*                                                                        *
*                        Automatic Grid Search                           *
*                                                                        *
*     The slopes were analyzed for failure arcs having centers in        *
*     areas defined by the following parallelograms:                     *
**************************************************************************
*                                                                        *
*                              Slope  1                                  *
*                                                                        *
*    Co-ord.        Point 1       Point 2       Point 3       Point 4    *
*    -------        -------       -------       -------       -------    *
*       X             456           424           408           440      *
*       Y             100            84           112           128      *
*------------------------------------------------------------------------*
*                              Slope  2                                  *
*                                                                        *
*    Co-ord.        Point 1       Point 2       Point 3       Point 4    *
*    -------        -------       -------       -------       -------    *
*       X             464           570           613           507      *
*       Y             107            64           139           182      *
*------------------------------------------------------------------------*
*                                                                        *
*       The number of divisions between points 1 and 2 were  4           *
*       The number of divisions between points 2 and 3 were  4           *
*       The X-increment used in the search was  . . . . . . 10           *
*       The Y-increment used in the search was  . . . . . . 10           *
*                                                                        *
**************************************************************************
```

```
*************************************************************************
*        R O T A T I O N A L   F A I L U R E   R E S U L T S            *
*************************************************************************
*          Hydraulic Condition: 2: Shallow Seepage                      *
*                                                                       *
*                Unconsolidated Undrained (UU) Case                     *
*-----------------------------------------------------------------------*
*             Safety         Failure          X-             Y-         *
*             Factor         Radius         Co-ord         Co-ord       *
*            --------       --------       --------       --------      *
*              1.24          109.9          530.3          149.9        *
*              1.24          107.4          530.3          147.4        *
*              1.24          112.4          530.3          152.4        *
*              1.24          114.9          530.3          154.9        *
*              1.24          109.9          532.8          149.9        *
*              1.24          112.4          532.8          152.4        *
*              1.24          109.9          527.8          149.9        *
*              1.25          102.4          532.8          142.4        *
*              1.25          112.4          527.8          152.4        *
*              1.26          122.4          532.8          162.4        *
*              1.26          112.4          535.3          152.4        *
*              1.28          112.4          522.8          152.4        *
*              1.28          112.4          522.8          152.4        *
*              1.28          131.3          533.5          171.3        *
*              1.34          112.4          542.8          152.4        *
*              1.36           93.6          512.0          133.6        *
*              1.44           82.9          538.5          122.9        *
*              1.49           22.0          440.0           94.5        *
*              1.52           64.1          527.8          104.1        *
*              1.54           74.8          501.3          114.8        *
*              1.56           24.4          440.0           97.0        *
*              1.56           90.7          496.3          163.2        *
*              1.57          101.7          549.3          141.7        *
*              1.67           19.7          440.0           92.0        *
*              1.67           19.7          440.0           92.0        *
*              1.70           21.3          442.5           94.5        *
*              1.72          142.0          507.0          182.0        *
*              1.75           22.8          437.5           94.5        *
*              1.77           70.1          485.5          144.4        *
*              1.77           27.4          436.0           99.0        *
*              1.79          120.5          560.0          160.5        *
*              1.94           19.0          442.5           92.0        *
*              1.95           45.3          517.0           85.3        *
*              1.96           56.0          490.5           96.0        *
*              2.07           53.3          554.3           93.3        *
*              2.12           35.1          432.0          106.0        *
*              2.13           20.5          437.5           92.0        *
*              2.20           34.5          543.5           74.5        *
*              2.29           49.5          474.8          125.6        *
*              2.38           42.8          428.0          113.0        *
*              2.43           72.1          565.0          112.1        *
*************************************************************************
```

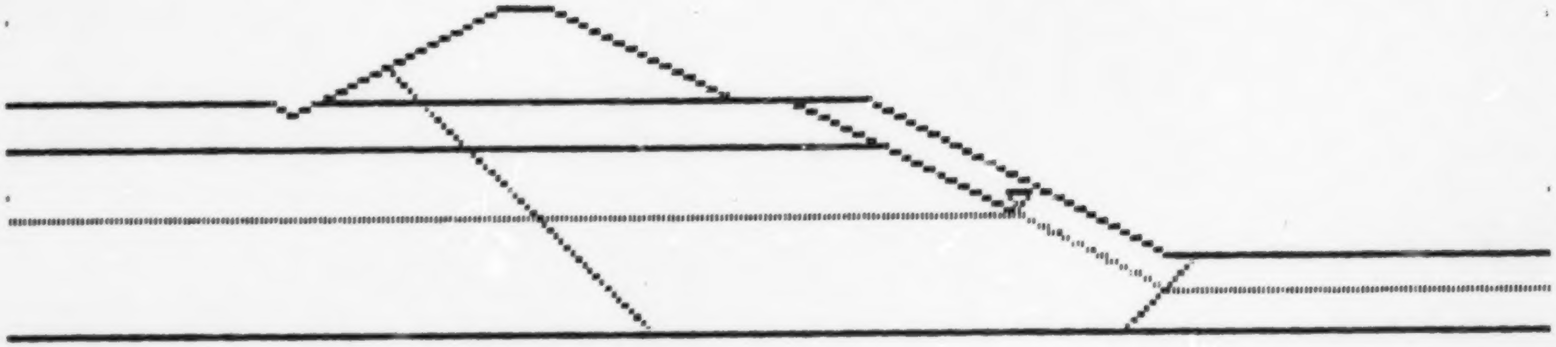
SHALLOW SEEPAGE CASE FOR EXAMPLE 1 File: BASE2EX1
Hydraulic Condition 2: Shallow Static Ground Water Table
Unconsolidated Undrained Soil Parameters
Factor of Safety = 1.24, Failure Center: (530 , 150), Radius: 110



(371 , 3) SCALE : 1 inch = 30 feet

```
*************************************************************************
*                                                                       *
*     T R A N S L A T I O N A L   F A I L U R E   R E S U L T S         *
*                                                                       *
*                                                                       *
*             Hydraulic Condition: 2: Shallow Seepage                   *
*                                                                       *
*                  Unconsolidated Undrained (UU) Case                   *
*                                                                       *
*            Central block endpoints automatically generated.           *
*                                                                       *
*                The minimum factor of safety is  1.13                  *
*                                                                       *
*-----------------------------------------------------------------------*
* Failure Surface    Xn           Yn           Xn+1          Yn+1       *
*   Segment #      Co-ord.      Co-ord.      Co-ord.       Co-ord.      *
*   --------       --------     --------     --------      --------     *
*       1           482.0        40.0         496.0          40.0       *
*       2           496.0        40.0         505.0          40.0       *
*       3           505.0        40.0         518.0          40.0       *
*       4           518.0        40.0         521.0          40.0       *
*       5           521.0        40.0         562.0          40.0       *
*       6           482.0        40.0         464.0          58.0       *
*       7           464.0        58.0         456.0          66.0       *
*       8           456.0        66.0         450.0          72.0       *
*       9           450.0        72.0         442.0          80.0       *
*      10           442.0        80.0         436.0          86.0       *
*      11           562.0        40.0         569.3          47.3       *
*      12           569.3        47.3         570.0          48.0       *
*      13           570.0        48.0         575.0          53.0       *
*************************************************************************
```

SHALLOW SEEPAGE CASE FOR EXAMPLE 1 File: BASE2EX1
Hydraulic Condition 2: Shallow Static Ground Water Table
Unconsolidated Undrained Soil Parameters
Factor of Safety = 1.13



(371 ,-27) SCALE : 1 inch = 30 feet

```
***********************************************************************
*      RECOMMENDED MINIMUM FACTOR OF SAFETY FOR SLOPE STABILITY      *
***********************************************************************
*                                 Confidence of          Recommended *
*  Shear Strength             Strength Measurement      Minimum F.S. *
*    Parameter                                                        *
*---------------------------------------------------------------------*
*  UU (end of construction, no        low                  1.40      *
*      waste or pool containment)     high                 1.20      *
*                                                                     *
*  CU                                 low                  1.50      *
*                                     high                 1.30      *
*                                                                     *
*  CU (drawdown pool condition)       low                  1.40      *
*                                     high                 1.20      *
*                                                                     *
*  CD (long-term, no seismic          low                  1.60      *
*      effects)                       high                 1.40      *
*                                                                     *
*  CD (long-term with seismic         low                  1.50      *
*      effects)                       high                 1.30      *
*                                                                     *
*  If the dike > 30 feet in height, add 0.10 to the F.S. in each case. *
***********************************************************************
```

```
************************************************************************
*                                                                      *
*                S E T T L E M E N T   R E S U L T S                   *
*                                                                      *
************************************************************************
*                    Settlement Beneath the Dike (ft)                  *
*----------------------------------------------------------------------*
* Layer Dike    Left        Left       Center       Right       Right  *
* Base Down      Toe        Crest       Line        Crest        Toe   *
* ----------   ------      ------      ------      ------      ------  *
*     2         0.03        0.33        0.33        0.33        0.03   *
*     3         0.06        0.21        0.21        0.21        0.06   *
*  ------      ------      ------      ------      ------      ------  *
*    SUM        0.09        0.53        0.54        0.53        0.09   *
*                                                                      *
************************************************************************
*                     Differential Settlement (ft)                     *
*----------------------------------------------------------------------*
*                                                                      *
*             Left Toe to Left Crest . . . . . .    0.44               *
*                                                                      *
*             Left Toe to Centerline . . . . . .    0.45               *
*                                                                      *
*             Left Crest to Centerline . . . . .    0.01               *
*                                                                      *
*             Right Crest to Centerline  . . . .    0.01               *
*                                                                      *
*             Right Toe to Right Crest . . . . .    0.44               *
*                                                                      *
*             Right Toe to Centerline  . . . . .    0.45               *
*                                                                      *
************************************************************************
```

```
************************************************************************
*              RECOMMENDED DIFFERENTIAL SETTLEMENT LIMITS              *
************************************************************************
*          Type                               Differential Limit       *
*----------------------------------------------------------------------*
*      Toe to Crest. . . . . . . . . . . . . . . . . 0.010 H           *
*                                                                      *
*      Crest to Centerline . . . . . . . . . . . . . 0.002 H           *
*                                                                      *
*      Toe to Centerline . . . . . . . . . . . . . . 0.012 H           *
*                                                                      *
*              where H = the maximum thickness of the dike             *
************************************************************************
```

```
************************************************************************
*                                                                      *
*              L I Q U E F A C T I O N    R E S U L T S                *
*                                                                      *
************************************************************************
*                                                                      *
*              Liquefaction analysis was not performed.                *
*                                                                      *
************************************************************************
```

```
**********************************************************************
*                                                                    *
*                     G A R D S   S U M M A R Y                      *
*                                                                    *
*   File:  BASE2EX1            Date: 01-01-1980    Time: 03:49:27    *
*   Project:  SHALLOW SEEPAGE CASE FOR EXAMPLE 1                     *
*   Hydraulic Condition 2: Shallow Seepage                           *
*                                                                    *
*--------------------------------------------------------------------*
*              Rotational Failure Analysis Safety Factor             *
*--------------------------------------------------------------------*
*       Unconsolidated Undrained Case . . . . . . . . . . .  1.24    *
*       Consolidated Drained Case . . . . . . . . . . . . . Not Run  *
*       Consolidated Undrained Case . . . . . . . . . . . . Not Run  *
*--------------------------------------------------------------------*
*             Translational Failure Analysis Safety Factor           *
*--------------------------------------------------------------------*
*       Unconsolidated Undrained Case . . . . . . . . . . .  1.13    *
*       Consolidated Drained Case . . . . . . . . . . . . . Not Run  *
*       Consolidated Undrained Case . . . . . . . . . . . . Not Run  *
*--------------------------------------------------------------------*
*               Settlement Analysis Feet of Settlement               *
*--------------------------------------------------------------------*
*       Maximum Settlement at the center line. . . . . .    0.54     *
*                                                                    *
*       Maximum Differential Settlement. . . . . . . . .    0.45     *
*       from the left toe to the centerline.                         *
*       Maximum Differential Settlement. . . . . . . . .    0.45     *
*       from the right toe to the centerline.                        *
*--------------------------------------------------------------------*
*       Liquefaction Analysis . . . . . . . . . . . . . Not Run      *
**********************************************************************
```

5.3 Evaluation of "BASE2EX1" Results

The results generated and reported in the preceeding Output Summary suggest that the proposed dike/cell structures cannot be safely constructed on the flood plain for at least two reasons:

1. Translation Slope Stability results unsatisfactory (F.S.<1.20)

2. Excessive differential settlement, both toe-to-crest and toe-to-centerline, on both sides of the dike (H = 16'; 0.01 H = 0.16', 0.012 H = 0.192')

The minimum factor of safety for Translational Slope Stability analysis using UU soil strength parameters was reported in the Output Summary as 1.13. This is slightly less than the recommended minimum for UU parameters for which the confidence of the strength measurement is judged to be high (1.20; see Table 2, p. 47).

Normally, at this point, the user would STOP and either abandon the site or re-design the Section to correct the above deficiencies before proceeding. For the sake of illustration, however, the Confined Pool Seepage case is addressed in the following subsection.

Recall that a liner uplift check was not performed (liner ignored in Shallow Seepage case) and that a liquefaction analysis was not performed (reserved for CD strength parameter case).

5.4 Confined Pool Seepage Analysis

At this point, the next logical analysis step might be to examine the Shallow Confined Seepage case (hydraulic boundary condition no. 4) in which the user would check both the potential for liner uplift and slope stability immediately after the liner was constructed. For the sake of expedience, however, this step is omitted in favor of the more complex Confined Pool Seepage case.

Using the Main Command Menu, the user would complete the analysis of the Confined Pool case as follows:

1. Copy in the BASE-2 file (3)

2. Call Hydraulics Analysis option (5)

   - specify Confined Pool Seepage case

   - input the elevation of the "maximum" upstream pool

   - input the design waste elevation in the cell

   - input the number of the soil representing the clay liner

3. Modify BASE-2 file for slope stability analysis (4)

   - rename the Project Identification as desired to reflect the new hydraulic condition (Confined Pool Seepage case for Example 1)

   - rename the data file to be saved along with all results for this case (BASE5EX1 used as new file name in this example)

   - change number of soil boundary lines from 5 to 7 to accommodate two new soils (upstream pool and waste in cell); redefine surface line (soil boundary line No. 7), and define soil boundary lines Nos. 5 (waste) and 6 (pool); enter soil properties for new waste and pool soils

   NOTE: Soil property changes for soil No. 3 (clay liner) are not necessary since the copied BASE-2 file contains the correct parameters for this soil.

4. Call Slope Stability analysis option (6)

   - specify rotational failure analysis

   - specify rotational failure search scheme (internally generated grid)

   - specify CD soil strength parameters

5. Recall Slope Stability Analysis option (6)

   - specify translational failure analysis

   - specify translational failure search scheme (automatic wedge search)

   - specify CD soil strength parameters

6. Call Liquefaction Analysis option (8)

7. Call Summary Output option (9)

8. Call Save File or Quit option (10); SAVE FILE!, return to main menu when prompted, or QUIT

Per Step 3 above, the following set of input data sheets include only the previous BASE-2 sheets which require modification and the new data sheets not previously used to create the BASE-2 file. The Summary Output for the Confined Pool Seepage condition (file BASE5EX1) follows the revised and new input data sheets.

Sheet 1 of 17

GARDS

Input Data Format

GENERAL INFORMATION

Project Identification: CONFINED POOL SEEPAGE CASE FOR EXAMPLE 1

Data File Name: BASE5EX1

Seismic Coefficient: - (no change)

Design Earthquake Magnitude: - (no change)

A complete data set for a given case consists of defining the basic geometry, soil properties, seepage conditions to be analyzed and the stability analysis options to be performed.

Forms for each of these criteria are provided. Use as many soil boundary line sheets as necessary to define the geometry, one soil boundary line per sheet. Also, use as many soil property sheets as necessary, one soil per sheet.

Sheet 2 of 17

A. DIKE GEOMETRY

Number of soil boundary lines for this section: 7

SOIL BOUNDARY LINE NO: 1

Number of points on soil boundary line #1 : 2 (no change)

POINT NO.	X-COORD	Y-COORD	POINT NO.	X-COORD	Y-COORD
1	(no change)		21		
2	(no change)		22		
3			23		
4			24		
5			25		
6			26		
7			27		
8			28		
9			29		
10			30		
11			31		
12			32		
13			33		
14			34		
15			35		
16			36		
17			37		
18			38		
19			39		
20			40		

(No change for soil boundary lines nos. 2, 3, 4)

SOIL BOUNDARY LINE NO: 5

Number of points on soil boundary line # 5 : 3

POINT NO.	X-COORD	Y-COORD	POINT NO.	X-COORD	Y-COORD
1	528	75	21		
2	570	53	22		
3	818	53	23		
4			24		
5			25		
6			26		
7			27		
8			28		
9			29		
10			30		
11			31		
12			32		
13			33		
14			34		
15			35		
16			36		
17			37		
18			38		
19			39		
20			40		

NOTE: Previously the entire surface line, now the base of waste layer.

Sheet 7 of 17

SOIL BOUNDARY LINE NO: 6

Number of points on soil boundary line # 6 : 5

POINT NO.	X-COORD	Y-COORD	POINT NO.	X-COORD	Y-COORD
1	0	80	21		
2	416	80	22		
3	420	78	23		
4	424	80	24		
5	440	88	25		
6			26		
7			27		
8			28		
9			29		
10			30		
11			31		
12			32		
13			33		
14			34		
15			35		
16			36		
17			37		
18			38		
19			39		
20			40		

NOTE: Previously part of the surface line, now the basal boundary line for a new upstream pool soil.

Sheet 8 of 17

SOIL BOUNDARY LINE NO: 7

Number of points on soil boundary line # 7 : 9

POINT NO.	X-COORD	Y-COORD	POINT NO.	X-COORD	Y-COORD
1	0	88	21		
2	440	88	22		
3	456	96	23		
4	464	96	24		
5	496	80	25		
6	505	80	26		
7	515	80	27		
8	528	75	28		
9	818	75	29		
10			30		
11			31		
12			32		
13			33		
14			34		
15			35		
16			36		
17			37		
18			38		
19			39		
20			40		

NOTE: New surface line for the Section

B. SOIL PROPERTIES

(No change for soils nos. 1, 2, 3, 4)

B. SOIL PROPERTIES

Soil No: 5

Cohesion:

unconsolidated, undrained (PSF) 0
or
1/2 unconfined compressive strength (PSF) -

consolidated, undrained (PSF) 0

consolidated, drained (PSF) 0

Angle of internal friction:

unconsolidated, undrained (degrees) 0

consolidated, undrained (degrees) 0

consolidated, drained (degrees) 0

Wet unit weight: (PCF) 100

Clay content: (%) 30

Overconsolidation ratio: 1.0

Initial void ratio: (decimal) 0.9

Compression index: (decimal) 0.01

Recompression index: (decimal) 0.005

Permeability: (ft/yr) 5000

D_{50}:(mm) 0.01

Plasticity index:(%) 17

Liquid limit:(%) 40

Average standard penetration resistance: (blows/ft) 5

NOTE: New "waste" soil; weight, but no strength, assumed.

B. SOIL PROPERTIES

Soil No: 6

Cohesion:

unconsolidated, undrained (PSF) or	0
1/2 unconfined compressive strength (PSF)	-
consolidated, undrained (PSF)	0
consolidated, drained (PSF)	0

Angle of internal friction:

unconsolidated, undrained (degrees)	0
consolidated, undrained (degrees)	0
consolidated, drained (degrees)	0
Wet unit weight: (PCF)	62.4
Clay content: (%)	0
Overconsolidation ratio:	1.0
Initial void ratio: (decimal)	0
Compression index: (decimal)	0
Recompression index: (decimal)	0
Permeability: (ft/yr)	0
D_{50}:(mm)	0
Plasticity index:(%)	0
Liquid limit:(%)	0
Average standard penetration resistance: (blows/ft)	0

NOTE: New upstream pool soil; weight, but no strength

C. DRAINAGE SPECIFICATION

Method of Input: x Internal Generation of Piezometric Surface

____ Manual Input of Piezometric Surface

INTERNAL GENERATION OF PHREATIC SURFACE

1. DEEP STATIC

Elevation of deep static groundwater table ____

2. SHALLOW SEEPAGE

Elevation of shallow seepage groundwater table ____

Soil number representing clay liner (0 if none) ____

3. FREE POOL SEEPAGE

Elevation of maximium upstream pool ____

Soil number representing clay liner (0 if none) ____

4. SHALLOW CONFINED SEEPAGE

Maximum shallow groundwater elevation ____

Design waste elevation in the cell ____

Soil number representing clay liner ____

5. CONFINED POOL SEEPAGE

Elevation of maximum upstream pool 88

Design waste elevation in the cell 75

Soil number representing clay liner 3

6. DRAWDOWN POOL

Elevation of maximum upstream pool ____

Soil number representing clay liner ____

NOTE: New hydraulic specification

D. ROTATIONAL FAILURE SEARCH SCHEMES

(no change)

E. TRANSLATIONAL FAILURE SEARCH SCHEMES

(no change)

F. SOIL STRENGTH PARAMETERS

UU ☐ unconsolidated - undrained
CU ☐ consolidated - undrained
CD ☒ consolidated - drained

G. OTHER STABILITY ANALYSES

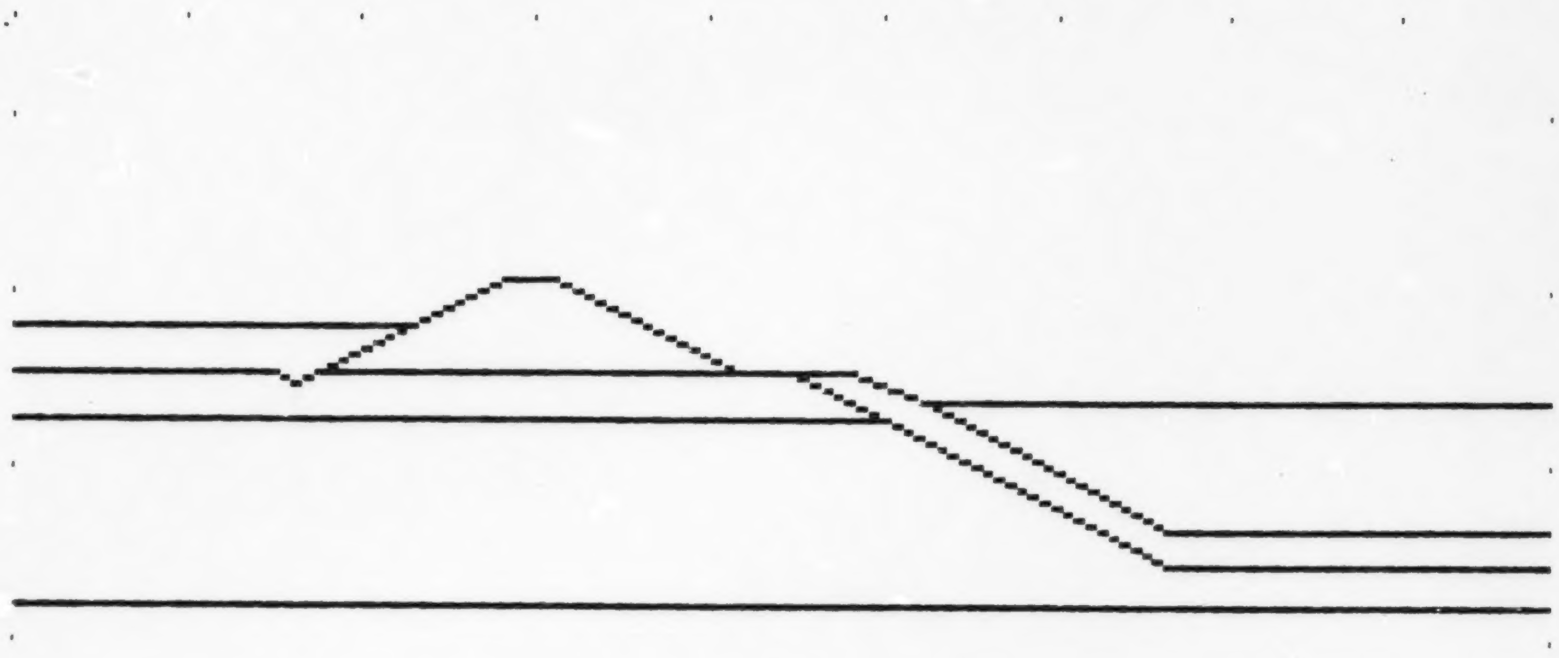
☐ settlement
☒ liquefaction

```
************************************************************************
*                                                                      *
*                      G A R D S   S U M M A R Y                       *
*                                                                      *
*    Project:  CONFINED POOL SEEPAGE CASE FOR EXAMPLE 1                *
*       File:  BASE5EX1                                                *
*                                                                      *
*                         GARDS  Version 2.00                          *
*                            developed by                              *
*          Department of Civil and Environmental Engineering           *
*                      University of Cincinnati                        *
*                          under contract to                           *
*                U.S. Environmental Protection Agency                  *
*                  Land Pollution Control Division                     *
*           Hazardous Waste Engineering Research Laboratory            *
*                                                                      *
************************************************************************
```

```
************************************************************************
*                        Site Characteristics                          *
************************************************************************
*                                                                      *
*      The seismic coefficient is. . . . . . . . . . . . . . 0.10      *
*                                                                      *
*      The design earthquake magnitude is. . . . . . . . . . 6.00      *
*                                                                      *
*      The maximum flood elevation in this case is . . . . .   88      *
*                                                                      *
*      The elevation of the seasonal high ground water is. .    0      *
*                                                                      *
*      The design waste elevation in the cell is . . . . . .   75      *
*                                                                      *
*      The soil number representing the clay liner is. . . .    3      *
*                                                                      *
************************************************************************
```

```
************************************************************************
*                            Section Geometry                          *
************************************************************************
*     The number of soil boundary lines for this section is  7         *
*----------------------------------------------------------------------*
*    Line  1        Point             X              Y                 *
*                   ------          ------         ------              *
*                     1                0             40                *
*                     2              818             40                *
*----------------------------------------------------------------------*
*    Line  2        Point             X              Y                 *
*                   ------          ------         ------              *
*                     1                0             72                *
*                     2              521             72                *
*----------------------------------------------------------------------*
*    Line  3        Point             X              Y                 *
*                   ------          ------         ------              *
*                     1              505             80                *
*                     2              521             72                *
*                     3              570             47                *
*                     4              818             47                *
*----------------------------------------------------------------------*
*    Line  4        Point             X              Y                 *
*                   ------          ------         ------              *
*                     1              424             80                *
*                     2              496             80                *
*----------------------------------------------------------------------*
*    Line  5        Point             X              Y                 *
*                   ------          ------         ------              *
*                     1              528             75                *
*                     2              570             53                *
*                     3              818             53                *
*----------------------------------------------------------------------*
*    Line  6        Point             X              Y                 *
*                   ------          ------         ------              *
*                     1                0             80                *
*                     2              416             80                *
*                     3              420             78                *
*                     4              424             80                *
*                     5              440             88                *
*----------------------------------------------------------------------*
*    Line  7        Point             X              Y                 *
*                   ------          ------         ------              *
*                     1                0             88                *
*                     2              440             88                *
*                     3              456             96                *
*                     4              464             96                *
*                     5              496             80                *
*                     6              505             80                *
*                     7              515             80                *
*                     8              528             75                *
*                     9              818             75                *
************************************************************************
```

CONFINED POOL SEEPAGE CASE FOR EXAMPLE 1 File: BASE5EX1
Hydraulic Condition 5: Confined Pool Seepage



(371 ,-27) SCALE ; 1 inch = 30 feet

```
************************************************************************
*                          Soil  1 Properties                          *
************************************************************************
*                                                                      *
*            Unconsolidated  Consolidated  Consolidated                *
*               Undrained     Undrained      Drained                   *
*             ------------  ------------  ------------                 *
*   Cohesion       1000          400           400        (lb/sq.ft)   *
*   Phi Angle        0            14            28         (degrees)   *
*----------------------------------------------------------------------*
*                                                                      *
*       Unit Weight . . . . . . . . . .  115.000   (lb/cu.ft)          *
*       Clay Content  . . . . . . . . .   35.000   (%)                 *
*       Overconsolidation Ratio . . . .    1.000                       *
*       Initial Void Ratio  . . . . . .    0.600                       *
*       Compression Index . . . . . . .    0.050                       *
*       Recompression Index . . . . . .    0.008                       *
*       Permeability  . . . . . . .        0.100   (ft/yr)             *
*       Median Grain Size . . . . . . .    0.002   (mm)                *
*       Plasticity Index  . . . . . . .    8.000   (%)                 *
*       Liquid Limit  . . . . . . . . .   25.000   (%)                 *
*       Standard Penetration Number . .   14.000   (blows/ft)          *
************************************************************************
```

```
************************************************************************
*                          Soil  2 Properties                          *
************************************************************************
*                                                                      *
*            Unconsolidated  Consolidated  Consolidated                *
*               Undrained     Undrained      Drained                   *
*             ------------  ------------  ------------                 *
*   Cohesion        200          150           150        (lb/sq.ft)   *
*   Phi Angle        0            16            30         (degrees)   *
*----------------------------------------------------------------------*
*                                                                      *
*       Unit Weight . . . . . . . . . .  110.000   (lb/cu.ft)          *
*       Clay Content  . . . . . . . . .   15.000   (%)                 *
*       Overconsolidation Ratio . . . .    1.000                       *
*       Initial Void Ratio  . . . . . .    0.450                       *
*       Compression Index . . . . . . .    0.080                       *
*       Recompression Index . . . . . .    0.010                       *
*       Permeability  . . . . . . .        0.250   (ft/yr)             *
*       Median Grain Size . . . . . . .    0.010   (mm)                *
*       Plasticity Index  . . . . . . .   10.000   (%)                 *
*       Liquid Limit  . . . . . . . . .   20.000   (%)                 *
*       Standard Penetration Number . .   16.000   (blows/ft)          *
************************************************************************
```

```
*************************************************************************
*                          Soil  3 Properties                           *
*************************************************************************
*                                                                       *
*             Unconsolidated  Consolidated  Consolidated                *
*               Undrained      Undrained      Drained                   *
*             ------------   ------------  ------------                 *
*  Cohesion       1300           900           1050        (lb/sq.ft)   *
*  Phi Angle        0             13             27         (degrees)   *
*-----------------------------------------------------------------------*
*                                                                       *
*        Unit Weight . . . . . . . . . . .  130.000   (lb/cu.ft)        *
*        Clay Content  . . . . . . . . . .   66.000   (%)               *
*        Overconsolidation Ratio . . . . .    1.000                     *
*        Initial Void Ratio  . . . . . . .    0.600                     *
*        Compression Index . . . . . . . .    0.250                     *
*        Recompression Index . . . . . . .    0.100                     *
*        Permeability  . . . . . . .          0.100   (ft/yr)           *
*        Median Grain Size . . . . . . . .    0.001   (mm)              *
*        Plasticity Index  . . . . . . . .   17.000   (%)               *
*        Liquid Limit  . . . . . . . . . .   38.000   (%)               *
*        Standard Penetration Number . . .   15.000   (blows/ft)        *
*************************************************************************
```

```
*************************************************************************
*                          Soil  4 Properties                           *
*************************************************************************
*                                                                       *
*             Unconsolidated  Consolidated  Consolidated                *
*               Undrained      Undrained      Drained                   *
*             ------------   ------------  ------------                 *
*  Cohesion       1200           600            600        (lb/sq.ft)   *
*  Phi Angle        0             14             29         (degrees)   *
*-----------------------------------------------------------------------*
*                                                                       *
*        Unit Weight . . . . . . . . . . .  128.000   (lb/cu.ft)        *
*        Clay Content  . . . . . . . . . .   55.000   (%)               *
*        Overconsolidation Ratio . . . . .    1.000                     *
*        Initial Void Ratio  . . . . . . .    0.700                     *
*        Compression Index . . . . . . . .    0.120                     *
*        Recompression Index . . . . . . .    0.020                     *
*        Permeability  . . . . . . .          0.100   (ft/yr)           *
*        Median Grain Size . . . . . . . .    0.001   (mm)              *
*        Plasticity Index  . . . . . . . .   18.000   (%)               *
*        Liquid Limit  . . . . . . . . . .   40.000   (%)               *
*        Standard Penetration Number . . .   10.000   (blows/ft)        *
*************************************************************************
```

```
************************************************************************
*                          Soil  5 Properties                          *
************************************************************************
*                                                                      *
*                                                                      *
*              Unconsolidated  Consolidated  Consolidated              *
*                 Undrained      Undrained      Drained                *
*                                                                      *
*              ------------   ------------   ------------              *
*   Cohesion          0              0              0     (lb/sq.ft)   *
*   Phi Angle         0              0              0      (degrees)   *
*----------------------------------------------------------------------*
*                                                                      *
*        Unit Weight . . . . . . . . . . .  100.000   (lb/cu.ft)       *
*        Clay Content  . . . . . . . . . .   30.000   (%)              *
*        Overconsolidation Ratio . . . . .    1.000                    *
*        Initial Void Ratio  . . . . . . .    0.900                    *
*        Compression Index . . . . . . . .    0.010                    *
*        Recompression Index . . . . . . .    0.005                    *
*        Permeability  . . . . . . . .     5000.000   (ft/yr)          *
*        Median Grain Size . . . . . . . .    0.010   (mm)             *
*        Plasticity Index  . . . . . . . .   17.000   (%)              *
*        Liquid Limit  . . . . . . . . . .   40.000   (%)              *
*        Standard Penetration Number . . .    5.000   (blows/ft)       *
************************************************************************
```

```
************************************************************************
*                          Soil  6 Properties                          *
************************************************************************
*                                                                      *
*                                                                      *
*              Unconsolidated  Consolidated  Consolidated              *
*                 Undrained      Undrained      Drained                *
*                                                                      *
*              ------------   ------------   ------------              *
*   Cohesion          0              0              0     (lb/sq.ft)   *
*   Phi Angle         0              0              0      (degrees)   *
*----------------------------------------------------------------------*
*                                                                      *
*        Unit Weight . . . . . . . . . . .   62.400   (lb/cu.ft)       *
*        Clay Content  . . . . . . . . . .    0.000   (%)              *
*        Overconsolidation Ratio . . . . .    1.000                    *
*        Initial Void Ratio  . . . . . . .    0.000                    *
*        Compression Index . . . . . . . .    0.000                    *
*        Recompression Index . . . . . . .    0.000                    *
*        Permeability  . . . . . . . .        0.000   (ft/yr)          *
*        Median Grain Size . . . . . . . .    0.000   (mm)             *
*        Plasticity Index  . . . . . . . .    0.000   (%)              *
*        Liquid Limit  . . . . . . . . . .    0.000   (%)              *
*        Standard Penetration Number . . .    0.000   (blows/ft)       *
************************************************************************
```

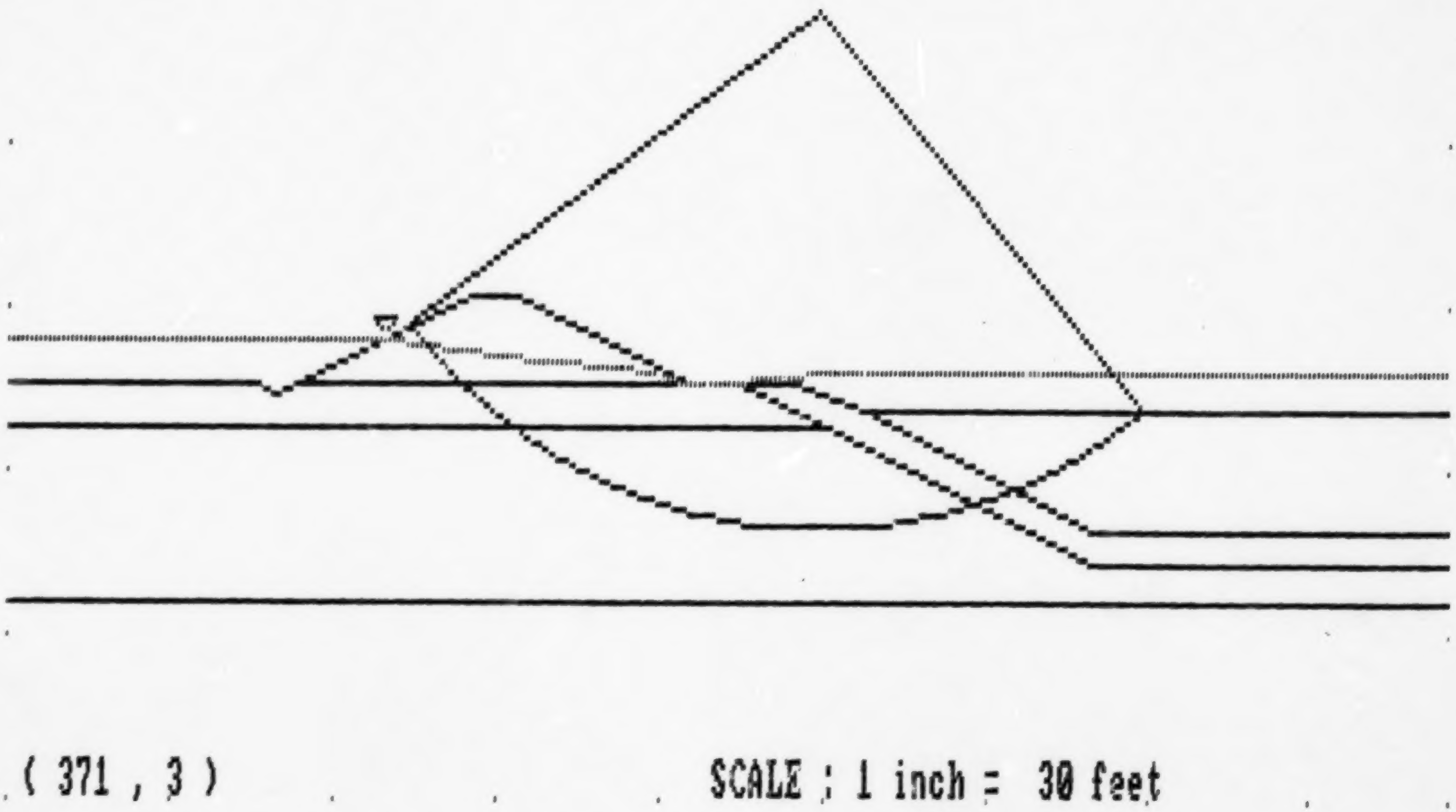
```
*************************************************************************
*                      Automatically Generated                          *
*             Piezometric Surface for Hydraulic Condition               *
*             5: Confined Pool Seepage                                  *
*************************************************************************
*                                                                       *
*                   Point            X             Y                    *
*                  ------        ------        ------                   *
*                       1             0            88                   *
*                       2           440            88                   *
*                       3           454            86                   *
*                       4           469            84                   *
*                       5           484            83                   *
*                       6           496            80                   *
*                       7           498            80                   *
*                       8           500            80                   *
*                       9           501            80                   *
*                      10           503            80                   *
*                      11           505            80                   *
*                      12           508            81                   *
*                      13           512            81                   *
*                      14           515            81                   *
*                      15           518            82                   *
*                      16           521            82                   *
*                      17           525            82                   *
*                      18           528            82                   *
*                      19           531            82                   *
*                      20           535            82                   *
*                      21           538            82                   *
*                      22           541            82                   *
*                      23           544            82                   *
*                      24           548            82                   *
*                      25           551            82                   *
*                      26           554            82                   *
*                      27           558            82                   *
*                      28           561            82                   *
*                      29           564            82                   *
*                      30           567            82                   *
*                      31           571            82                   *
*                      32           574            82                   *
*                      33           577            82                   *
*                      34           581            82                   *
*                      35           584            82                   *
*                      36           818            82                   *
*************************************************************************
```

```
***********************************************************************
*                        Hydraulics Results                           *
***********************************************************************
*                                                                     *
*        Seepage In . . . . . . . .     140.616   (cu.ft/yr)          *
*                                                                     *
*        Seepage Out . . . . . . . .   -140.069   (cu.ft/yr)          *
*                                                                     *
*        Critical Exit Gradient . . .     0.295                       *
*                                                                     *
*             Liner Uplift Potential for Hydraulic Condition          *
*             5: Confined Pool Seepage                                *
*---------------------------------------------------------------------*
*                   X-            Y-           Safety                 *
*                 Coord.        Coord.         Factor                 *
*                -------       -------        -------                 *
*                  528.0          68.3          0.91                  *
*                  531.3          66.7          0.97                  *
*                  534.5          65.0          1.01                  *
*                  524.7          70.0          1.03                  *
*                  537.8          63.3          1.04                  *
*                  541.1          61.7          1.07                  *
*                  544.4          60.0          1.10                  *
*                  547.7          58.3          1.12                  *
*                  551.0          56.7          1.14                  *
*                  554.2          55.0          1.16                  *
*                  557.5          53.3          1.17                  *
*                  560.8          51.7          1.19                  *
*                  564.1          50.0          1.20                  *
*                  567.4          48.3          1.21                  *
*                  521.4          71.7          1.22                  *
*                  570.7          46.7          1.22                  *
*                  573.9          45.0          1.23                  *
*                  508.3          78.3          1.23                  *
*                  577.2          43.3          1.24                  *
*                  580.5          41.7          1.24                  *
*                  583.8          40.0          1.25                  *
*                  511.6          76.7          1.37                  *
*                  514.8          75.0          1.45                  *
*                  518.1          73.3          1.49                  *
*                                                                     *
***********************************************************************
```

```
************************************************************************
*                                                                      *
*        R O T A T I O N A L   F A I L U R E   R E S U L T S           *
*                                                                      *
*                       Automatic Grid Search                          *
*                                                                      *
*    The slopes were analyzed for failure arcs having centers in       *
*    areas defined by the following parallelograms:                    *
************************************************************************
*                                                                      *
*                              Slope  1                                *
*                                                                      *
*    Co-ord.       Point 1       Point 2       Point 3       Point 4   *
*    -------       -------       -------       -------       -------   *
*       X            456           440           432           448     *
*       Y             98            90           104           112     *
*----------------------------------------------------------------------*
*                              Slope  2                                *
*                                                                      *
*    Co-ord.       Point 1       Point 2       Point 3       Point 4   *
*    -------       -------       -------       -------       -------   *
*       X            464           528           549           485     *
*       Y            101            80           117           138     *
*----------------------------------------------------------------------*
*                                                                      *
*       The number of divisions between points 1 and 2 were  4         *
*       The number of divisions between points 2 and 3 were  4         *
*       The X-increment used in the search was  . . . . . . 10         *
*       The Y-increment used in the search was  . . . . . . 10         *
*                                                                      *
************************************************************************
```

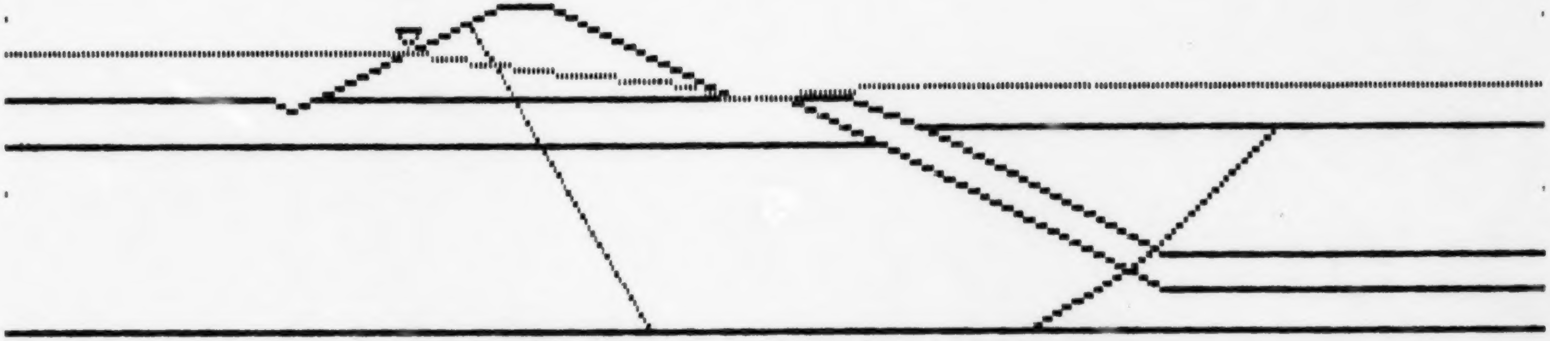
```
************************************************************************
*                                                                      *
*         R O T A T I O N A L   F A I L U R E   R E S U L T S          *
*                                                                      *
************************************************************************
*                                                                      *
*            Hydraulic Condition: 5: Confined Pool Seepage             *
*                                                                      *
*                    Consolidated Drained (CD) Case                    *
*                    Seismic Coefficient = 0.10                        *
*----------------------------------------------------------------------*
*           Safety        Failure         X-            Y-             *
*           Factor        Radius        Co-ord        Co-ord           *
*          --------      --------      --------      --------          *
*             1.79          94.2          519.5         147.5          *
*             1.79          96.7          519.5         150.0          *
*             1.79          91.7          519.5         145.0          *
*             1.79          94.3          522.0         147.5          *
*             1.79          94.2          517.0         147.5          *
*             1.80          84.2          517.0         137.5          *
*             1.80         101.0          527.0         147.5          *
*             1.81         104.2          517.0         157.5          *
*             1.84          74.2          517.0         127.5          *
*             1.84          74.2          517.0         127.5          *
*             1.85          74.1          507.0         127.5          *
*             1.87          86.4          507.0         147.5          *
*             1.88          65.0          511.8         118.3          *
*             1.90          33.5          485.3         105.2          *
*             1.91          71.1          501.0         132.8          *
*             1.93          87.5          527.0         127.5          *
*             1.97          55.8          506.5         109.1          *
*             1.99          23.4          480.0          96.0          *
*             2.01          61.2          495.8         123.6          *
*             2.03          34.5          432.0         106.5          *
*             2.03          32.0          432.0         104.0          *
*             2.03          32.0          432.0         104.0          *
*             2.04          32.0          434.5         104.0          *
*             2.05          28.5          434.0         100.5          *
*             2.05          25.0          436.0          97.0          *
*             2.08          34.5          429.5         106.5          *
*             2.09          73.1          527.8         113.1          *
*             2.10          82.3          533.0         122.3          *
*             2.11          43.6          490.5         114.4          *
*             2.13          32.0          429.5         104.0          *
*             2.17          46.6          501.3          99.9          *
*             2.19          53.9          479.8         128.8          *
*             2.21          63.9          522.5         103.9          *
*             2.22          64.0          485.0         138.0          *
*             2.45          54.7          517.3          94.7          *
*             2.49          35.3          444.0         110.0          *
************************************************************************
```

CONFINED POOL SEEPAGE CASE FOR EXAMPLE 1 File: BASE5EX1
Hydraulic Condition 5: Confined Pool Seepage
Consolidated Drained Soil Parameters
Factor of Safety = 1.79, Failure Center: (520 , 148), Radius: 94


(371 , 3)
SCALE : 1 inch = 30 feet

```
*************************************************************************
*                                                                       *
*    T R A N S L A T I O N A L   F A I L U R E   R E S U L T S          *
*                                                                       *
*                                                                       *
*             Hydraulic Condition: 5: Confined Pool Seepage             *
*                                                                       *
*                   Consolidated Drained (CD) Case                      *
*                   Seismic Coefficient = 0.10                          *
*                                                                       *
*            Central block endpoints automatically generated.           *
*                                                                       *
*                 The minimum factor of safety is  1.61                 *
*                                                                       *
*-----------------------------------------------------------------------*
* Failure Surface     Xn           Yn            Xn+1          Yn+1     *
*   Segment #      Co-ord.      Co-ord.        Co-ord.       Co-ord.    *
*   --------       --------     --------       --------      --------   *
*       1           482.0         40.0          496.0          40.0     *
*       2           496.0         40.0          505.0          40.0     *
*       3           505.0         40.0          515.0          40.0     *
*       4           515.0         40.0          521.0          40.0     *
*       5           521.0         40.0          528.0          40.0     *
*       6           528.0         40.0          546.0          40.0     *
*       7           482.0         40.0          464.0          70.0     *
*       8           464.0         70.0          462.8          72.0     *
*       9           462.8         72.0          458.2          80.0     *
*      10           458.2         80.0          456.0          83.7     *
*      11           456.0         83.7          450.4          93.2     *
*      12           546.0         40.0          563.3          50.4     *
*      13           563.3         50.4          568.7          53.7     *
*      14           568.7         53.7          590.0          75.0     *
*************************************************************************
```

CONFINED POOL SEEPAGE CASE FOR EXAMPLE 1 File: BASE5EX1
Hydraulic Condition 5: Confined Pool Seepage
Consolidated Drained Soil Parameters
Factor of Safety = 1.61



(371 ,-27) SCALE : 1 inch = 30 feet

```
************************************************************************
*       RECOMMENDED MINIMUM FACTOR OF SAFETY FOR SLOPE STABILITY       *
************************************************************************
*  Shear Strength                 Confidence of          Recommended   *
*    Parameter                Strength Measurement       Minimum F.S.  *
*----------------------------------------------------------------------*
*  UU (end of construction, no          low                  1.40      *
*      waste or pool containment)       high                 1.20      *
*                                                                      *
*  CU                                   low                  1.50      *
*                                       high                 1.30      *
*                                                                      *
*  CU (drawdown pool condition)         low                  1.40      *
*                                       high                 1.20      *
*                                                                      *
*  CD (long-term, no seismic            low                  1.60      *
*      effects)                         high                 1.40      *
*                                                                      *
*  CD (long-term with seismic           low                  1.50      *
*      effects)                         high                 1.30      *
*                                                                      *
*  If the dike > 30 feet in height, add 0.10 to the F.S. in each case. *
************************************************************************
```

```
************************************************************************
*                                                                      *
*                 S E T T L E M E N T    R E S U L T S                 *
*                                                                      *
*                 Settlement analysis was not performed.               *
*                                                                      *
************************************************************************
```

```
************************************************************************
*                                                                      *
*              L I Q U E F A C T I O N   R E S U L T S                 *
*                                                                      *
************************************************************************
*                                                                      *
*                     Seismic Coefficient = 0.10                       *
*                                                                      *
*                   Soil          Surface       Safety                 *
*                   Layer         Point #       Factor                 *
*                  -------       -------       -------                 *
*                     2             7             1.58                 *
*                     2             5             1.76                 *
*                     2             6             1.76                 *
*                     2             2             2.11                 *
*                     2             3             3.45                 *
*                     2             4             3.51                 *
*                                                                      *
************************************************************************
```

```
**************************************************************************
*                                                                        *
*                      G A R D S   S U M M A R Y                         *
*                                                                        *
*   File:  BASE5EX1              Date: 01-01-1980    Time: 03:56:39      *
*   Project:  CONFINED POOL SEEPAGE CASE FOR EXAMPLE 1                   *
*   Hydraulic Condition 5: Confined Pool Seepage                         *
*                                                                        *
*------------------------------------------------------------------------*
*               Rotational Failure Analysis Safety Factor                *
*------------------------------------------------------------------------*
*        Unconsolidated Undrained Case . . . . . . . . . Not Run         *
*        Consolidated Drained Case . . . . . . . . . . . Not Run         *
*        Consolidated Undrained Case . . . . . . . . . .  1.79           *
*------------------------------------------------------------------------*
*              Translational Failure Analysis Safety Factor              *
*------------------------------------------------------------------------*
*        Unconsolidated Undrained Case . . . . . . . . . Not Run         *
*        Consolidated Drained Case . . . . . . . . . . . Not Run         *
*        Consolidated Undrained Case . . . . . . . . . .  1.61           *
*------------------------------------------------------------------------*
*              Settlement Analysis . . . . . . . . . . . Not Run         *
*------------------------------------------------------------------------*
*        Liquefaction Analysis Safety Factor . . . . . . .  1.58         *
**************************************************************************
```

5.5 Evaluation of "BASE5EX1" Results

A review of the GARDS Summary indicates that the factor of safety for rotational slope stability, translational slope stability, and liquefaction are all within acceptable limits for the CD soil strength case.

The only significant deficiency for this Section is the potential for liner failure (uplift) for the upstream pool elevation assumed. A review of the Hydraulics Results (p. 116) indicates that liner uplift will occur beneath the waste stratum along the upstream wall of the lined cell between X-coordinates 528.0 and 534.0, and may occur up to about X-coordinate 544.

The liner uplift problem may be overcome by:

- increasing the thickness of the liner along the upstream wall of the cell,

  OR

- avoiding the impoundment of an upstream pool until such time as the cell is completely filled with waste,

  OR

- lowering the upstream pool for the liner and waste configuration tested in this case

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APPENDIX A

SEISMIC PARAMETERS

Figure 1. Seismic Risk Map of the U.S.
Figure 2. Seismic Source Zones in Contiguous U.S.
Table 1. Seismic Parameters for Source Zones

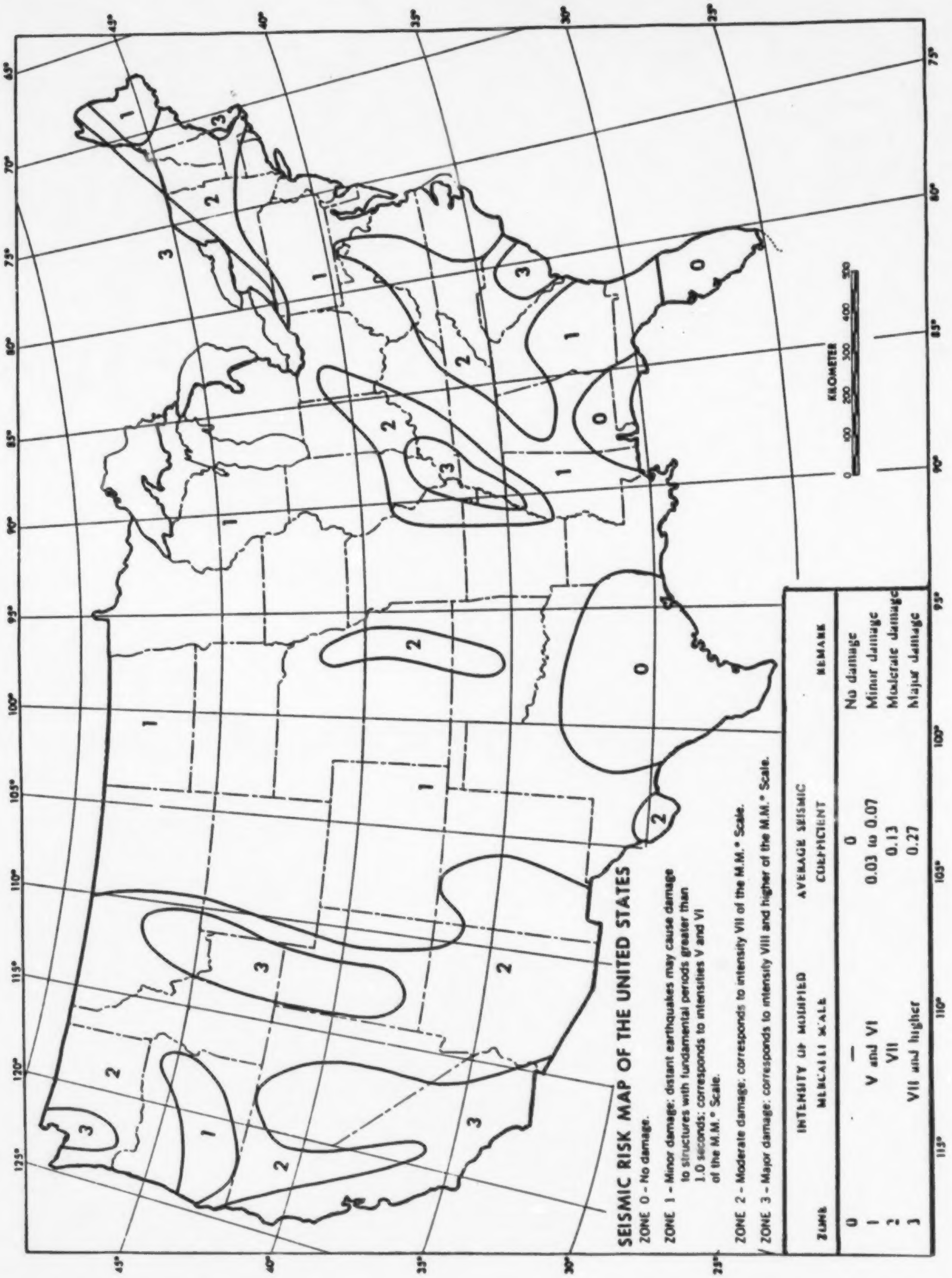
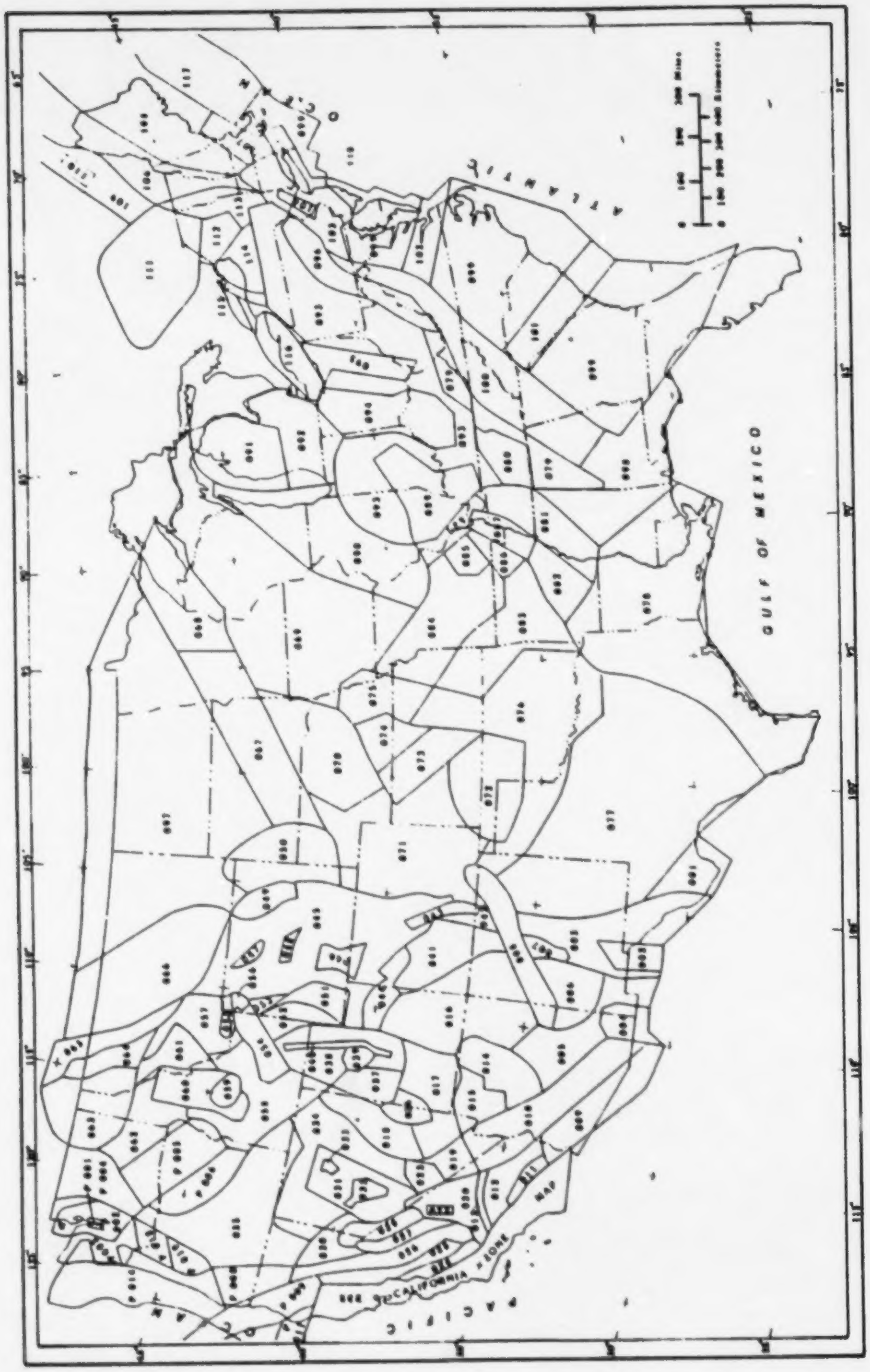

SEISMIC RISK MAP OF THE UNITED STATES
ZONE 0 - No damage.
ZONE 1 - Minor damage; distant earthquakes may cause damage to structures with fundamental periods greater than 1.0 seconds; corresponds to intensities V and VI of the M.M.* Scale.
ZONE 2 - Moderate damage; corresponds to intensity VII of the M.M.* Scale.
ZONE 3 - Major damage; corresponds to intensity VIII and higher of the M.M.* Scale.
ZONE
INTENSITY OF MODIFIED MERCALLI SCALE
AVERAGE SEISMIC COEFFICIENT
REMARK
0
—
0
No damage
1
V and VI
0.03 to 0.07
Minor damage
2
VII
0.13
Moderate damage
3
VIII and higher
0.27
Major damage
KILOMETER
0
100
200
300
400
500
0
1
2
3
45°
40°
35°
30°
25°
65°
70°
75°
80°
85°
90°
95°
100°
105°
110°
115°
120°
125°

Figure 1. Seismic Risk Map of the United States



ATLANTIC OCEAN
GULF OF MEXICO
PACIFIC OCEAN
CALIFORNIA ZONE MAP

Figure 2. Seismic source zones in the contiguous United States.

TABLE 1. SEISMIC PARAMETERS FOR SOURCE ZONES

ZONE NO*	MAXIMUM MAGNITUDE M**	ZONE NO	MAXIMUM MAGNITUDE M	ZONE NO	MAXIMUM MAGNITUDE M	ZONE NO	MAXIMUM MAGNITUDE M
p001	7.3	c027	7.3	032	6.1	076	6.1
p002	7.3	c028	7.3	033	6.1	077	6.1
p003	7.3	c029	7.3	034	7.3	078	
p004	7.3	c030	6.7	035	7.3	079	
p005	7.3	c031	6.7	036	6.1	080	
p006	7.3	c032	7.9	037	7.3	081	
p008	7.3	c033	7.9	038	7.3	082	
p009	7.9	c034	7.9	039	7.3	083	
p010	7.9	c035	7.3	040	7.3	084	
p011	7.9	c036	6.7	041	7.3	085	
p012	7.9	c037	6.1	042	6.1	086	
p013	7.9	c038	7.9	043	7.3	087	
p014	7.3	c039	7.9	044	6.1	088	
p015	7.3	c040	6.1	045	6.1	089	
p016	7.3	c041	7.9	046	6.1	090	
p017	7.9	001	7.3	047	6.1	091	
p018	7.3	002	7.3	048	6.1	092	
p019	7.3	003	6.1	049	6.1	093	
c001	7.3	004	7.3	050	6.1	094	
c002	7.3	005	7.3	051	6.1	095	
c003	7.3	006	7.3	052	7.3	096	
c004	7.3	007	7.3	053	7.3	097	
c005	6.1	008	6.1	054	6.1	098	
c006	7.3	009	6.1	055	7.3	099	
c007	7.3	010	7.3	056	6.1	100	
c008	6.1	011	7.3	057	7.3	101	
c009	6.1	012	7.3	058	7.3	102	
c010	6.1	013	7.3	059	6.1	103	
c011	7.3	014	7.3	060	6.1	104	
c012	7.3	015	6.7	061	7.3	106	
c013	7.3	016	6.1	062	6.1	107	
c014	7.9	017	7.3	063	6.1	108	
c015	7.9	018	7.3	064	7.3	109	
c016	7.9	019	7.3	065	6.1	110	
c017	7.3	020	7.3	066	6.1	111	
c018	7.3	022	6.1	067	6.1	112	
c019	6.7	023	7.3	068	6.1	113	
c020	6.1	024	7.3	069	6.1	114	
c021	6.1	025	6.1	070	6.1	115	
c022	6.1	026	6.1	071	6.1	116	
c023	7.9	027	5.5	072	6.1	117	
c024	8.5	029	7.3	073	6.1	118	
c025	7.3	030	7.3	074	6.1		
c026	7.3	031	7.3	075	6.1		

---

*Zones are shwon in Figures 2 & 3
**See page 46 for definition of M

APPENDIX B

GARDS FLOW CHARTS

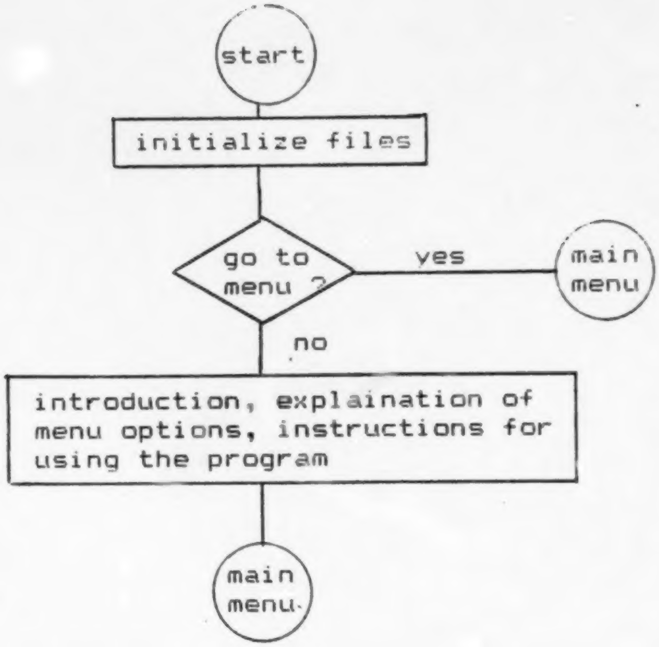

start
initialize files
go to menu ?
yes
main menu
no
introduction, explaination of menu options, instructions for using the program
main menu

Figure B-1. Macro flow chart of GARDS 'Start' module

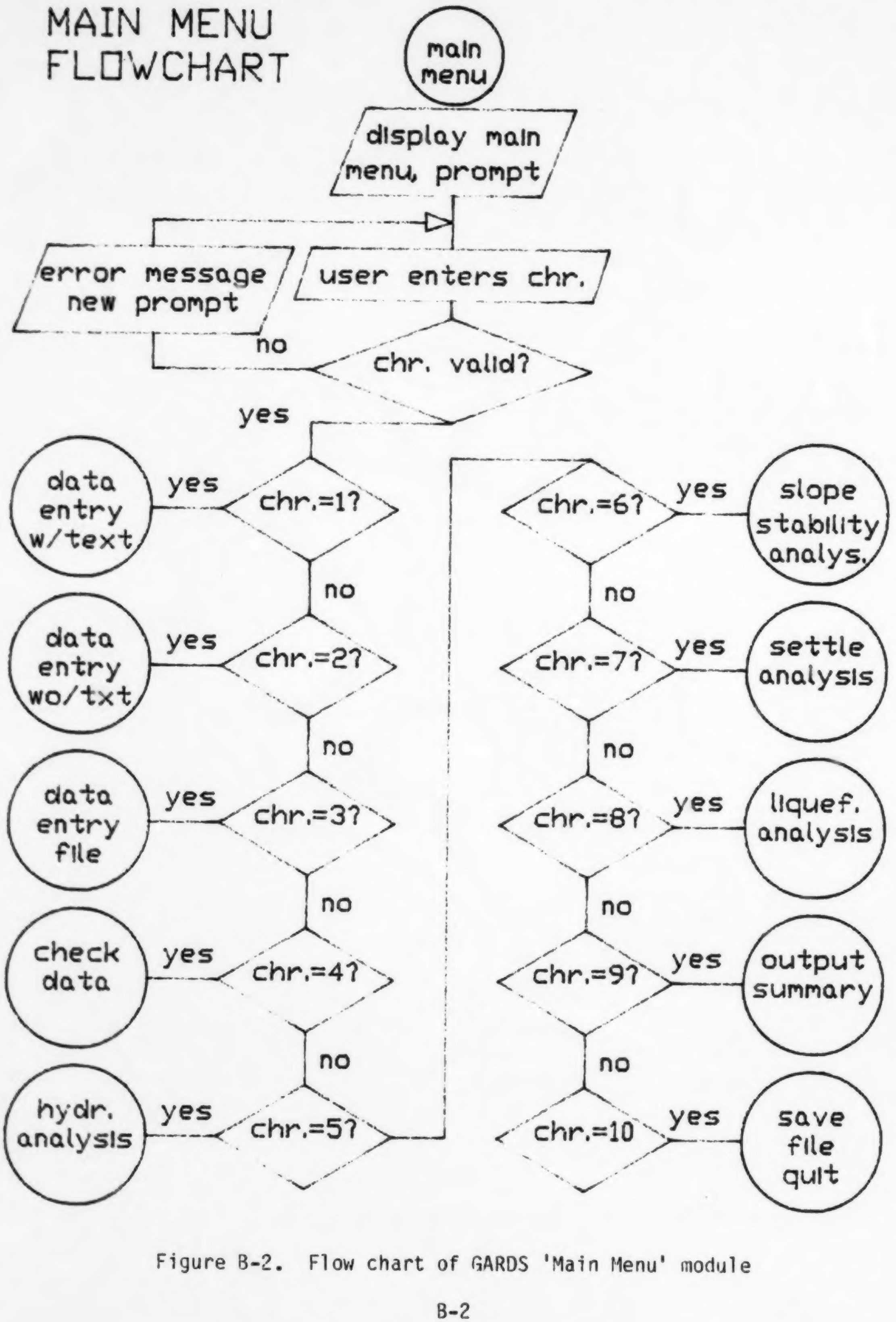
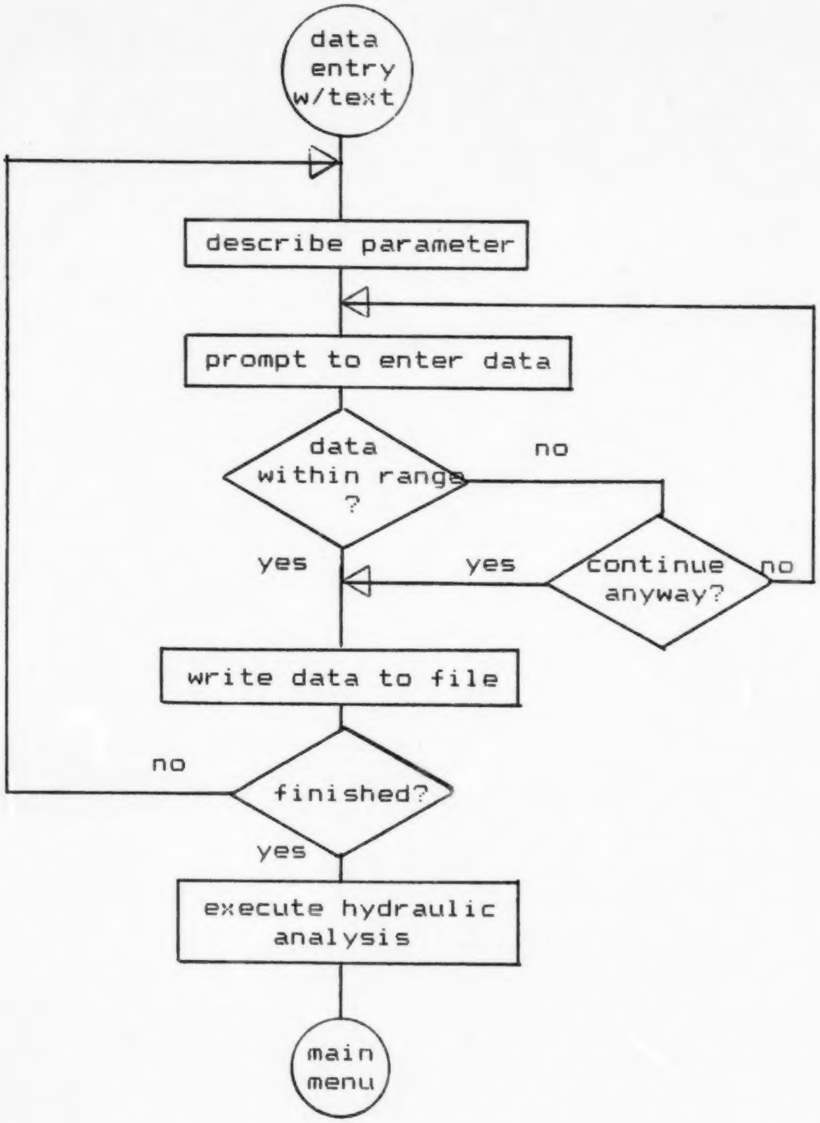

MAIN MENU
FLOWCHART
main menu
display main menu, prompt
error message new prompt
user enters chr.
no
chr. valid?
yes
data entry w/text
yes
chr.=1?
no
data entry wo/txt
yes
chr.=2?
no
data entry file
yes
chr.=3?
no
check data
yes
chr.=4?
no
hydr. analysis
yes
chr.=5?
chr.=6?
yes
slope stability analys.
no
chr.=7?
yes
settle analysis
no
chr.=8?
yes
liquef. analysis
no
chr.=9?
yes
output summary
no
chr.=10
yes
save file quit

Figure B-2. Flow chart of GARDS 'Main Menu' module


data entry w/text
describe parameter
prompt to enter data
data within range ?
no
yes
continue anyway?
yes
no
write data to file
finished?
no
yes
execute hydraulic analysis
main menu

B-3. Macro flow chart of GARDS 'Initial Data Entry with Text Explanations' module

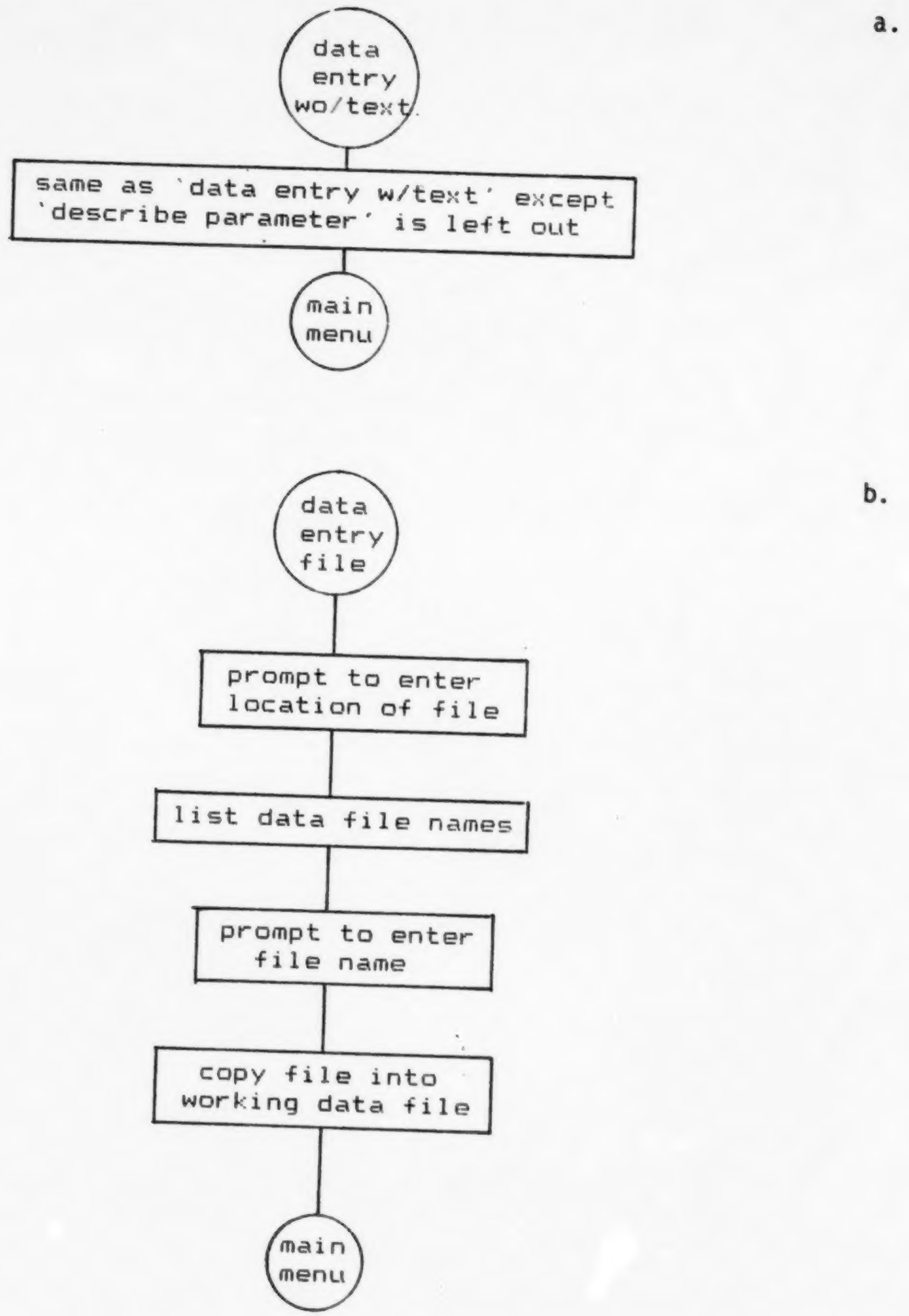

a.
data entry wo/text
same as 'data entry w/text' except 'describe parameter' is left out
main menu
b.
data entry file
prompt to enter location of file
list data file names
prompt to enter file name
copy file into working data file
main menu

Figure B-4. Macro flow chart of GARDS, a: 'Initial Data Entry Without Text' and b: 'Data Entry Using an Existing Data File' module

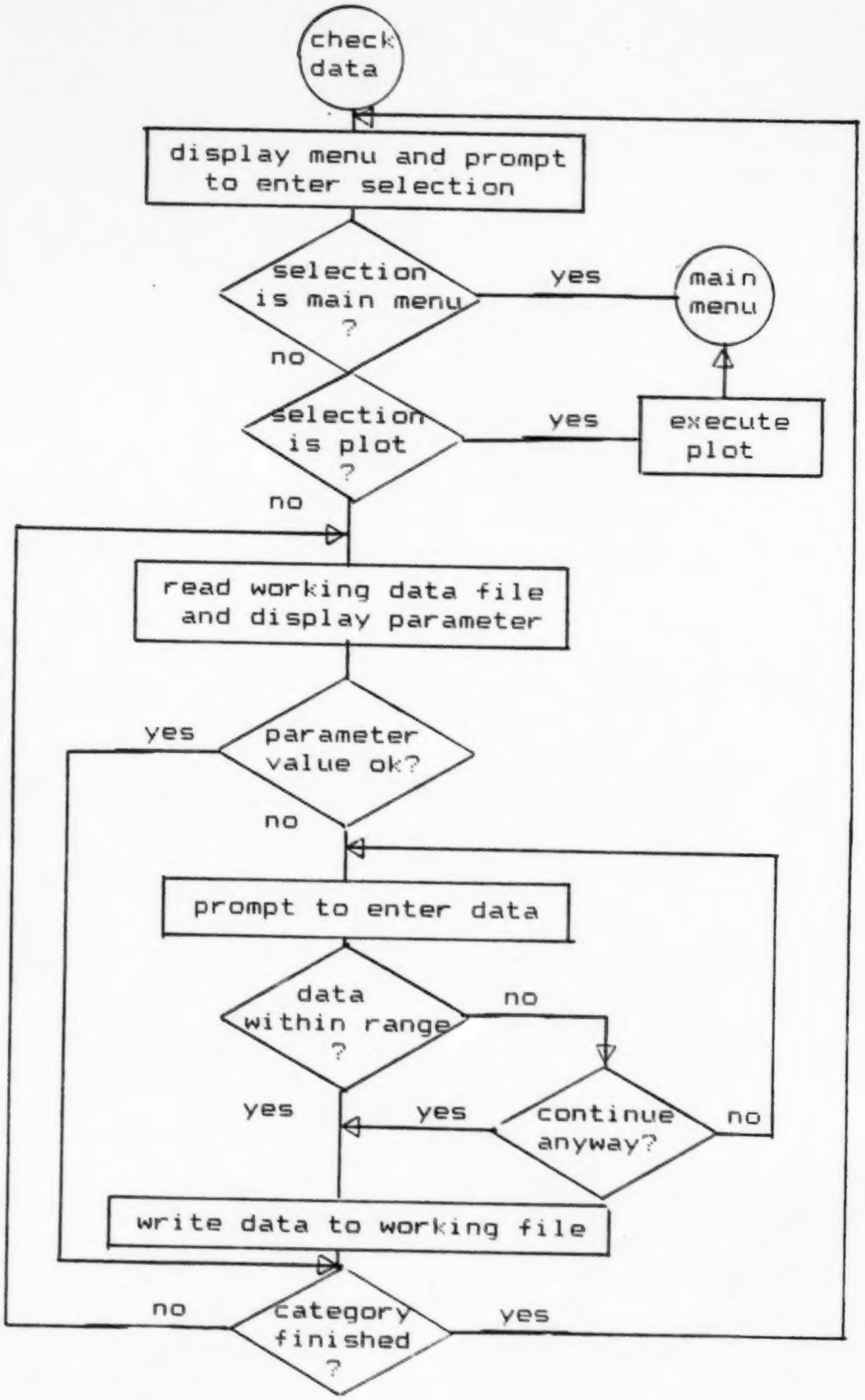

check data
display menu and prompt to enter selection
selection is main menu ?
yes
main menu
no
selection is plot ?
yes
execute plot
no
read working data file and display parameter
yes
parameter value ok?
no
prompt to enter data
data within range ?
no
continue anyway?
yes
yes
no
write data to working file
no
category finished ?
yes

Figure B-5. Macro flow chart of GARDS 'Check or Edit Input Data' module

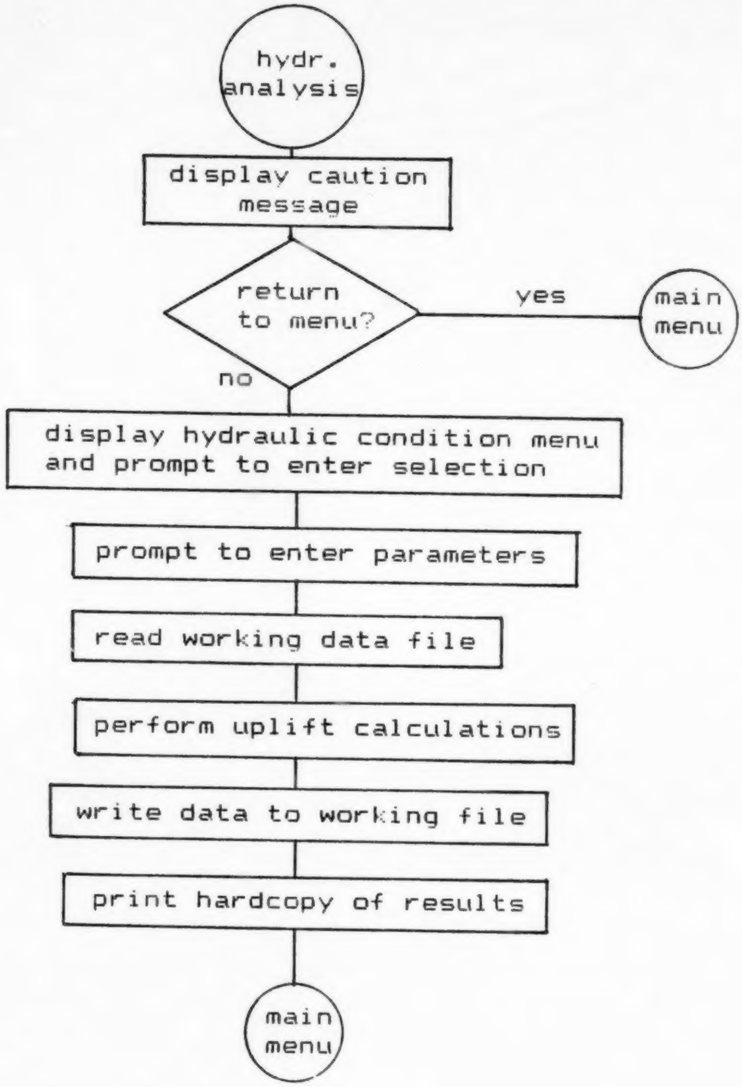

hydr. analysis
display caution message
return to menu?
yes
main menu
no
display hydraulic condition menu and prompt to enter selection
prompt to enter parameters
read working data file
perform uplift calculations
write data to working file
print hardcopy of results
main menu

Figure B-6. Macro flow chart of GARDS "Hydraulics Analysis' module

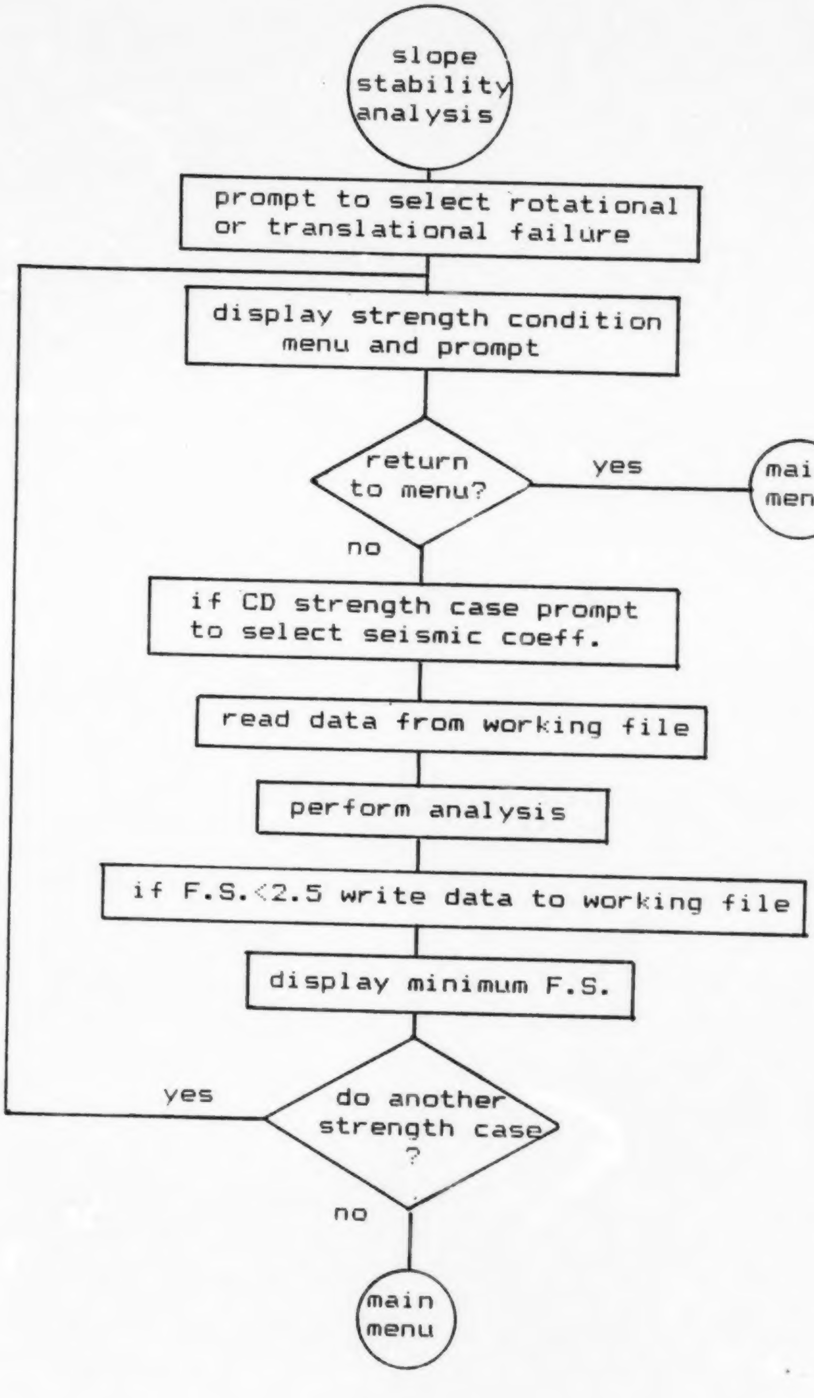

slope stability analysis
prompt to select rotational or translational failure
display strength condition menu and prompt
return to menu?
yes
main menu
no
if CD strength case prompt to select seismic coeff.
read data from working file
perform analysis
if F.S.<2.5 write data to working file
display minimum F.S.
yes
do another strength case ?
no
main menu

Figure B-7. Macro flow chart of GARDS 'Slope Stability Analysis' module

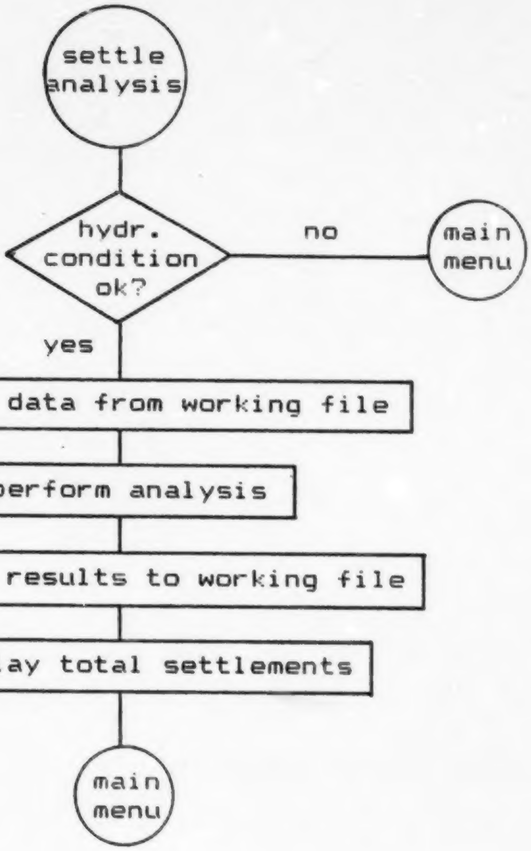

settle analysis
hydr. condition ok?
no
main menu
yes
read data from working file
perform analysis
write results to working file
display total settlements
main menu

Figure B-8. Macro flow chart of GARDS 'Settlement Analysis' module

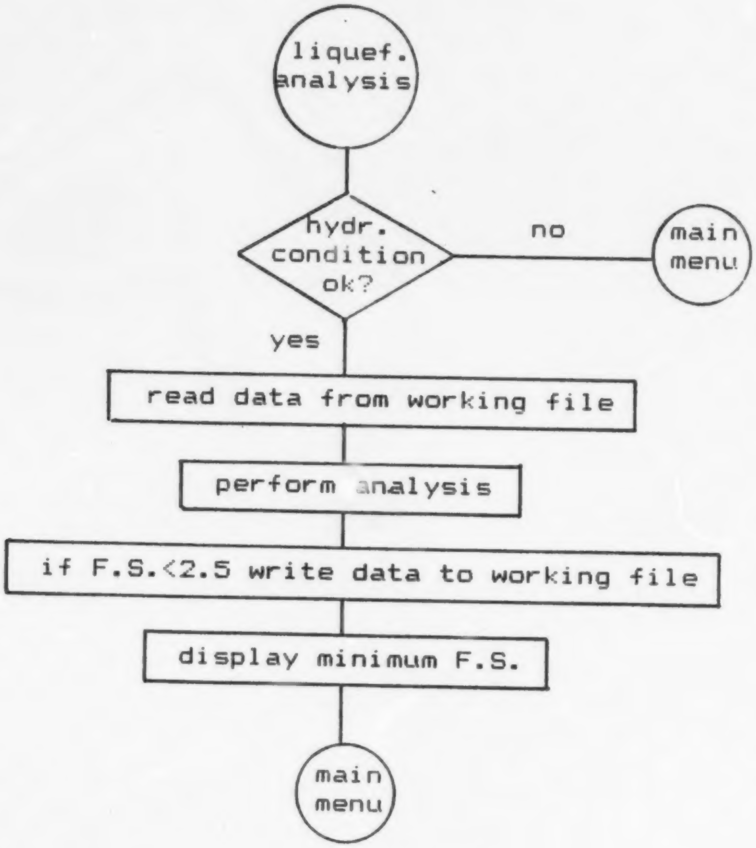

liquef. analysis
hydr. condition ok?
no
main menu
yes
read data from working file
perform analysis
if F.S.<2.5 write data to working file
display minimum F.S.
main menu

Figure B-9. Macro flow chart of GARDS 'Liquefaction Analysis' module

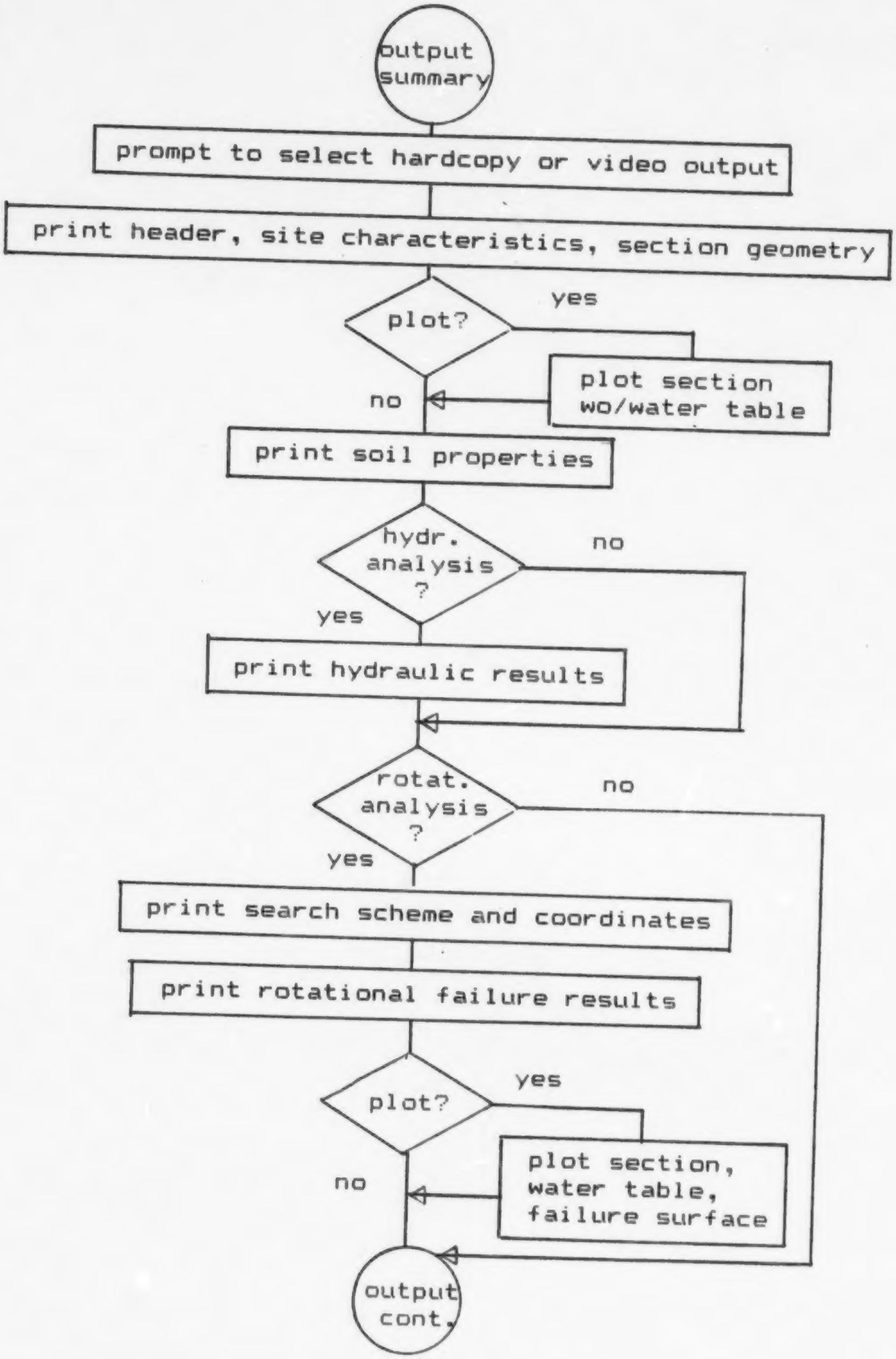

output summary
prompt to select hardcopy or video output
print header, site characteristics, section geometry
plot?
yes
plot section wo/water table
no
print soil properties
hydr. analysis ?
no
yes
print hydraulic results
rotat. analysis ?
no
yes
print search scheme and coordinates
print rotational failure results
plot?
yes
plot section, water table, failure surface
no
output cont.

Figure B-10. Macro flow chart of GARDS 'Output Summary' module

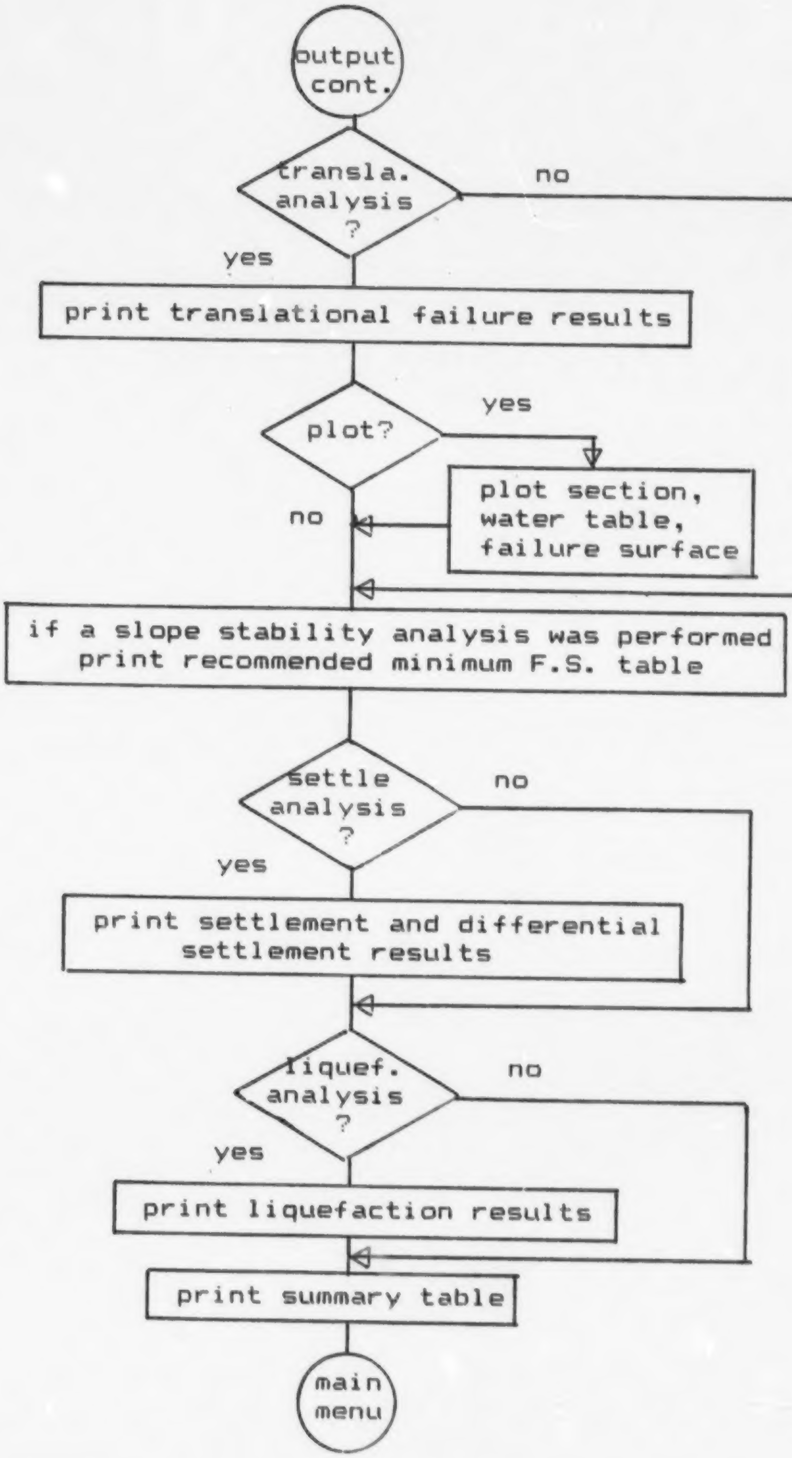

output cont.
transla. analysis ?
no
yes
print translational failure results
plot?
yes
no
plot section, water table, failure surface
if a slope stability analysis was performed print recommended minimum F.S. table
settle analysis ?
no
yes
print settlement and differential settlement results
liquef. analysis ?
no
yes
print liquefaction results
print summary table
main menu

Figure B-10 (cont.). Macro flow chart of GARDS 'Output Summary' module

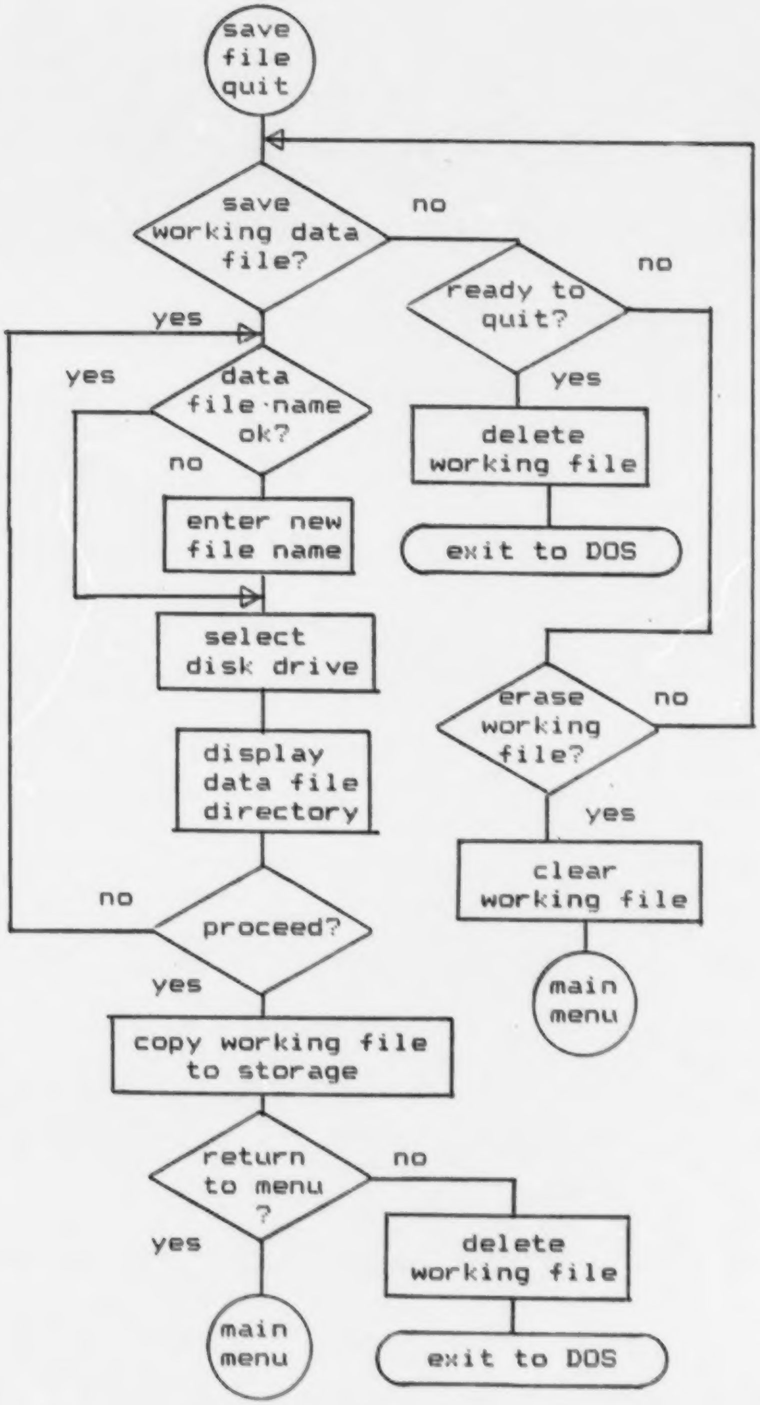

save file quit
save working data file?
no
yes
ready to quit?
no
yes
delete working file
exit to DOS
data file name ok?
yes
no
enter new file name
select disk drive
display data file directory
erase working file?
no
yes
clear working file
main menu
proceed?
no
yes
copy working file to storage
return to menu ?
no
yes
delete working file
main menu
exit to DOS

Figure B-11. Macro flow chart of GARDS 'Save File or Quit' module

APPENDIX C

INPUT DATA FORMS
(Two Sets)

Sheet 1 of ___

GARDS

Input Data Format

GENERAL INFORMATION

Project Identification:______________________________

Data File Name:______________________________

Seismic Coefficient:______________________________

Design Earthquake Magnitude:______________________________

A complete data set for a given case consists of defining the basic geometry, soil properties, seepage conditions to be analyzed and the stability analysis options to be performed.

Forms for each of these criteria are provided. Use as many soil boundary line sheets as necessary to define the geometry, one soil boundary line per sheet. Also, use as many soil property sheets as necessary, one soil per sheet.

Sheet ___ of ___

A. DIKE GEOMETRY

Number of soil boundary lines for this section:______

SOIL BOUNDARY LINE NO: 1

Number of points on soil boundary line #1 : ___

POINT NO.	X-COORD	Y-COORD	POINT NO.	X-COORD	Y-COORD
1	______	______	21	______	______
2	______	______	22	______	______
3	______	______	23	______	______
4	______	______	24	______	______
5	______	______	25	______	______
6	______	______	26	______	______
7	______	______	27	______	______
8	______	______	28	______	______
9	______	______	29	______	______
10	______	______	30	______	______
11	______	______	31	______	______
12	______	______	32	______	______
13	______	______	33	______	______
14	______	______	34	______	______
15	______	______	35	______	______
16	______	______	36	______	______
17	______	______	37	______	______
18	______	______	38	______	______
19	______	______	39	______	______
20	______	______	40	______	______

Sheet ___ of ___

B. SOIL PROPERTIES

Soil No: _____

Cohesion:

|‾ unconsolidated, undrained (PSF) ________________

or

|_ 1/2 unconfined compressive strength (PSF) ________________

consolidated, undrained (PSF) ________________

consolidated, drained (PSF) ________________

Angle of internal friction:

unconsolidated, undrained (degrees) ________________

consolidated, undrained (degrees) ________________

consolidated, drained (degrees) ________________

Wet unit weight: (PCF) ________________

Clay content: (%) ________________

Overconsolidation ratio: ________________

Initial void ratio: (decimal) ________________

Compression index: (decimal) ________________

Recompression index: (decimal) ________________

Permeability: (ft/yr) ________________

D_{50}:(mm) ________________

Plasticity index:(%) ________________

Liquid limit:(%) ________________

Average standard penetration resistance: (blows/ft) ________________

Sheet ___ of ___

C. DRAINAGE SPECIFICATION

Method of Input: _____ Internal Generation of Piezometric Surface

_____ Manual Input of Piezometric Surface

INTERNAL GENERATION OF PHREATIC SURFACE

1. DEEP STATIC

Elevation of deep static groundwater table____________________________

2. SHALLOW SEEPAGE

Elevation of shallow seepage groundwater table________________________

Soil number representing clay liner (0 if none)________________________

3. FREE POOL SEEPAGE

Elevation of maximium upstream pool__________________________________

Soil number representing clay liner (0 if none)________________________

4. SHALLOW CONFINED SEEPAGE

Maximum shallow groundwater elevation________________________________

Design waste elevation in the cell____________________________________

Soil number representing clay liner__________________________________

5. CONFINED POOL SEEPAGE

Elevation of maximum upstream pool___________________________________

Design waste elevation in the cell____________________________________

Soil number representing clay liner__________________________________

6. DRAWDOWN POOL

Elevation of maximum upstream pool___________________________________

Soil number representing clay liner__________________________________

Sheet ___ of ___

MANUAL INPUT OF PHREATIC SURFACE

POINT NO.	X-COORD	Y-COORD	POINT NO.	X-COORD	Y-COORD
1	______	______	21	______	______
2	______	______	22	______	______
3	______	______	23	______	______
4	______	______	24	______	______
5	______	______	25	______	______
6	______	______	26	______	______
7	______	______	27	______	______
8	______	______	28	______	______
9	______	______	29	______	______
10	______	______	30	______	______
11	______	______	31	______	______
12	______	______	32	______	______
13	______	______	33	______	______
14	______	______	34	______	______
15	______	______	35	______	______
16	______	______	36	______	______
17	______	______	37	______	______
18	______	______	38	______	______
19	______	______	39	______	______
20	______	______	40	______	______

Sheet ___ of ___

D. ROTATIONAL FAILURE SEARCH SCHEMES

☒ Internally generated grid search

☐ User defined grid search

Grid Point No.	X-Coordinate	Y-Coordinate
1	___	___
2	___	___
3	___	___

Number of divisions between points #1 and #2: ___

Number of divisions between points #2 and #3: ___

X-increment for search: ___

Y-increment for search: ___

☐ User defined point search

Number of centers to be analyzed: ___

Point No.	X-Coordinate	Y-Coordinate
1	___	___
2	___	___
3	___	___
4	___	___
5	___	___

X-increment for search: ___

Y-increment for search: ___

E. TRANSLATIONAL FAILURE (WEDGE) SEARCH SCHEMES

☐ Automatic wedge search

--------------- ---

☐ User defined wedge

X-coordinate left side of central block ___________

X-coordinate right side of central block ___________

F. SOIL STRENGTH PARAMETERS

UU ☐ unconsolidated - undrained

CU ☐ consolidated - undrained

CD ☐ consolidated - drained

G. OTHER STABILITY ANALYSES

☐ settlement

☐ liquefaction

Sheet ___ of ___

SOIL BOUNDARY LINE NO: ___

Number of points on soil boundary line #___ : ___

POINT NO.	X-COORD	Y-COORD	POINT NO.	X-COORD	Y-COORD
1	___	___	21	___	___
2	___	___	22	___	___
3	___	___	23	___	___
4	___	___	24	___	___
5	___	___	25	___	___
6	___	___	26	___	___
7	___	___	27	___	___
8	___	___	28	___	___
9	___	___	29	___	___
10	___	___	30	___	___
11	___	___	31	___	___
12	___	___	32	___	___
13	___	___	33	___	___
14	___	___	34	___	___
15	___	___	35	___	___
16	___	___	36	___	___
17	___	___	37	___	___
18	___	___	38	___	___
19	___	___	39	___	___
20	___	___	40	___	___

Sheet ___ of ___

B. SOIL PROPERTIES

Soil No: _____

Cohesion:

unconsolidated, undrained (PSF) ____________________

or

1/2 unconfined compressive strength (PSF) ____________________

consolidated, undrained (PSF) ____________________

consolidated, drained (PSF) ____________________

Angle of internal friction:

unconsolidated, undrained (degrees) ____________________

consolidated, undrained (degrees) ____________________

consolidated, drained (degrees) ____________________

Wet unit weight: (PCF) ____________________

Clay content: (%) ____________________

Overconsolidation ratio: ____________________

Initial void ratio: (decimal) ____________________

Compression index: (decimal) ____________________

Recompression index: (decimal) ____________________

Permeability: (ft/yr) ____________________

D_{50}:(mm) ____________________

Plasticity index:(%) ____________________

Liquid limit:(%) ____________________

Average standard penetration resistance: (blows/ft) ____________________

Sheet ___ of ___

C. DRAINAGE SPECIFICATION

Method of Input: _____ Internal Generation of Piezometric Surface

_____ Manual Input of Piezometric Surface

INTERNAL GENERATION OF PHREATIC SURFACE

1. DEEP STATIC

Elevation of deep static groundwater table______________________________

2. SHALLOW SEEPAGE

Elevation of shallow seepage groundwater table_________________________

Soil number representing clay liner (0 if none)________________________

3. FREE POOL SEEPAGE

Elevation of maximium upstream pool_____________________________________

Soil number representing clay liner (0 if none)________________________

4. SHALLOW CONFINED SEEPAGE

Maximum shallow groundwater elevation___________________________________

Design waste elevation in the cell______________________________________

Soil number representing clay liner_____________________________________

5. CONFINED POOL SEEPAGE

Elevation of maximum upstream pool______________________________________

Design waste elevation in the cell______________________________________

Soil number representing clay liner_____________________________________

6. DRAWDOWN POOL

Elevation of maximum upstream pool______________________________________

Soil number representing clay liner_____________________________________

Sheet ___ of ___

MANUAL INPUT OF PHREATIC SURFACE

POINT NO.	X-COORD	Y-COORD	POINT NO.	X-COORD	Y-COORD
1			21		
2			22		
3			23		
4			24		
5			25		
6			26		
7			27		
8			28		
9			29		
10			30		
11			31		
12			32		
13			33		
14			34		
15			35		
16			36		
17			37		
18			38		
19			39		
20			40		

Sheet ___ of ___

D. ROTATIONAL FAILURE SEARCH SCHEMES

☒ Internally generated grid search

☐ User defined grid search

Grid Point No.	X-Coordinate	Y-Coordinate
1	______	______
2	______	______
3	______	______

Number of divisions between points #1 and #2: ______

Number of divisions between points #2 and #3: ______

X-increment for search: ______

Y-increment for search: ______

☐ User defined point search

Number of centers to be analyzed: ______

Point No.	X-Coordinate	Y-Coordinate
1	______	______
2	______	______
3	______	______
4	______	______
5	______	______

X-increment for search: ______

Y-increment for search: ______

Sheet ___ of ___

E. TRANSLATIONAL FAILURE (WEDGE) SEARCH SCHEMES

☐ Automatic wedge search

--------------- --

☐ User defined wedge

X-coordinate left side of central block ____________
X-coordinate right side of central block ____________

F. SOIL STRENGTH PARAMETERS

UU ☐ unconsolidated - undrained

CU ☐ consolidated - undrained

CD ☐ consolidated - drained

G. OTHER STABILITY ANALYSES

☐ settlement

☐ liquefaction

Sheet 1 of ___

GARDS

Input Data Format

GENERAL INFORMATION

Project Identification:______________________________

Data File Name:______________________________

Seismic Coefficient:______________________________

Design Earthquake Magnitude:______________________________

A complete data set for a given case consists of defining the basic geometry, soil properties, seepage conditions to be analyzed and the stability analysis options to be performed.

Forms for each of these criteria are provided. Use as many soil boundary line sheets as necessary to define the geometry, one soil boundary line per sheet. Also, use as many soil property sheets as necessary, one soil per sheet.

Sheet ___ of ___

A. DIKE GEOMETRY

Number of soil boundary lines for this section:______

SOIL BOUNDARY LINE NO: 1

Number of points on soil boundary line #1 : ___

POINT NO.	X-COORD	Y-COORD	POINT NO.	X-COORD	Y-COORD
1	______	______	21	______	______
2	______	______	22	______	______
3	______	______	23	______	______
4	______	______	24	______	______
5	______	______	25	______	______
6	______	______	26	______	______
7	______	______	27	______	______
8	______	______	28	______	______
9	______	______	29	______	______
10	______	______	30	______	______
11	______	______	31	______	______
12	______	______	32	______	______
13	______	______	33	______	______
14	______	______	34	______	______
15	______	______	35	______	______
16	______	______	36	______	______
17	______	______	37	______	______
18	______	______	38	______	______
19	______	______	39	______	______
20	______	______	40	______	______

Sheet ___ of ___

SOIL BOUNDARY LINE NO: ___

Number of points on soil boundary line #___ : ___

POINT NO.	X-COORD	Y-COORD	POINT NO.	X-COORD	Y-COORD
1			21		
2			22		
3			23		
4			24		
5			25		
6			26		
7			27		
8			28		
9			29		
10			30		
11			31		
12			32		
13			33		
14			34		
15			35		
16			36		
17			37		
18			38		
19			39		
20			40		